EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/88-155
November 9th, 1988

Construction and Performance of a Position Detector for the UA1 Uranium - TMP Calorimeter

UA1 Collaboration, CERN, Geneva, Switzerland

Aachen¹ – Amsterdam (NIKHEF)² – Annecy (LAPP)³ – Birmingham⁴ – CERN⁵ – Harvard⁶
– Helsinki⁷ – Kiel⁸ – Imperial College, London⁹ – Queen Mary College, London¹⁰ – Madrid
(CIEMAT)¹¹ – MIT¹² – Padua¹³ – Paris (College de France)¹⁴ – Riverside¹⁵ – Rome¹⁶ –
Rutherford Appleton Lab¹⁷ – Saclay (CEN)¹⁸ – UCLA¹⁹ – Vienna²⁰

K. Ankoviak¹⁹, G. Bauer⁶, C. Buchanan¹⁹, D. Cline¹⁹, A. Di Ciaccio¹⁶, H. Evans¹⁹,
T. A. Fuess¹², S. Geer⁶, A. Gonidec⁵, J. Gronberg¹⁹, M. Lindgren¹⁵, M. Mohammadi¹⁹,
L. Naumann⁵, E. Radermacher⁵, J.-P. Revol¹², J. Rohlf⁶, C. Rubbia⁵, E. Sadowski⁶,
D. Schinzel⁵, C. Seez⁹, W. Seidl⁵, D. Stork¹⁹, K. Sumorok⁶, S. Tether¹², X. Wu¹²

ABSTRACT

A full-scale prototype position detector has been built and tested for the Uranium - Tetramethylpentane (TMP) calorimeter which is presently being constructed for the UA1 experiment at the CERN proton-antiproton collider. The position detector consists of a sealed stainless steel box containing TMP and three electrode planes, where the middle plane is used for energy measurement, and the other two are highly segmented to enable a precise measurement of the position of electromagnetic showers. The position detector has been operated in electron and muon test beams at CERN. The detector performs well, both as an element of the calorimeter and as a device for measuring shower positions, and yields a spatial resolution of about 1mm for high energy electron showers.

Presented at the International Conference on Advanced Technology and Particle Physics,
Como, Italy, 13-17 June 1988

[Proceedings published by Nucl. Instr. & Methods]

1. Introduction

The proton-antiproton collider complex at CERN has recently been improved with the addition of a dedicated antiproton collector ring (ACOL [1]). To exploit the high luminosities provided by the upgraded collider, a major improvement of the UA1 detector [2] was proposed [3]. The main component of the UA1 upgrade is the replacement of the original lead-scintillator electromagnetic sampling calorimeter [4] with a fine-grained Uranium-TMP (2,2,4,4 Tetramethylpentane) room-temperature-liquid sampling calorimeter. A cross-section of a module in the central part of this new calorimeter is shown in Figure 1. Stainless steel boxes containing the TMP are sandwiched between uranium plates. Inside each box a plane of central electrodes is maintained at positive high voltage. Ionization electrons liberated in the liquid by traversing charged particles drift towards the central electrodes, and are detected by observing the signal induced on the electrodes. The boxes in the calorimeter module are organized into six groups (samplings 1 to 6). After sampling 1, which contains five TMP boxes interleaved between five 2 mm thick uranium plates, there is a special TMP box designed to make a precise measurement of the position of electromagnetic showers as well as sampling their energy. This position detector layer contains highly segmented electrode planes and is located at a depth of 3.5 radiation lengths (at normal incidence) in the calorimeter, which approximately optimizes one and two shower resolution over the range of the collider shower energies. This paper describes the construction of a full-scale prototype TMP position detector and its performance as determined from measurements in electron and muon test beams.

2. Position Detector Prototype Construction

The design of the prototype UA1 Uranium-TMP position detector box described in this paper is an extension of the design of the normal TMP boxes in the upgraded UA1 calorimeter. The position detector box has been constructed by laser welding 150 μm stainless steel sheets onto a steel bar frame 541.0 mm long, 226.5 mm wide, and 6.5 mm thick. The parameters of

the position detector box are summarized in Table 1. Inside the box (Figure 2) there are three electrode planes. A plane of eight central electrodes is sandwiched between a plane of 24 "long" strip electrodes parallel to the long side of the box, and 58 "short" strip electrodes parallel to the short side of the box. All electrodes are made from 500 μm stainless steel, and are separated and held in place by ceramic spacers. The drift gap between neighbouring electrode planes, and between the strip planes and the nearby skin of the box, is 1.25 mm. The eight central electrodes have dimensions 107 mm by 130 mm. The long (short) strips are 521 mm (213 mm) long and 7 mm wide, and the strip pitch is 9.1 mm. The electrodes are connected to the outside world via ceramic high voltage feedthroughs, designed to hold a potential difference of 3 kV between the feedthrough wire and the box skin. The prototype position detector was constructed at Hutchinson Technology Incorporated (a USA company building both the calorimeter and the position detector boxes for the UA1 upgrade), and filled with TMP at CERN. Figure 3 shows an assembled position detector on an aluminum support plate. The feedthroughs for short and long strips can be seen.

To enable the position detector to be filled with TMP there are two fill tubes on one of the long thin sides of the box. The free end of these tubes is attached to a valve via a flange. After filling the valves are closed, isolating the TMP in the box from the outside world. The challenge in building a TMP calorimeter is to obtain ultra-pure TMP (containing less than a few parts per billion electron trapping impurities) and to keep it pure. This requires the box to have a leak rate of less than 10^{-8} Torr.liter/sec to preserve the purity of TMP. The purification procedure used for the liquid, the cleaning procedures used for the construction materials (steel and ceramics), the final bake out and the vacuum test of the box, and the method of filling the box with TMP are equivalent to the procedures used for the calorimeter boxes, and are described in references [3, 5, 6].

3. Operation and Readout

The prototype position detector was operated with the central electrodes and the skin at ground, and the strip electrodes at positive high voltage (the final configuration in the

experiment will have the strips at ground, and the central electrodes and the skin at positive high voltage). Free electrons in the liquid drift towards the strips under the influence of the uniform electric field in the 1.25 mm drift gaps between neighbouring electrode planes. The passage of a minimum ionizing particle (MIP) through the box creates a signal equivalent to that of approximately 2000 free electrons drifting across the gap at a field of 8 kV/cm.

A total of 16 strips were instrumented in a matrix of 8 short by 8 long strips. The readout was decoupled from the high voltage on each strip with a 4.7 nF capacitor. Signals were integrated using a preamplifier of the type designed for the DELPHI calorimeter [7]. This preamplifier has low noise at low detector capacitance, and is thus suitable for use with the position detector, which has a capacitance of 52 (126) pF per short (long) strip. A shaping amplifier with a 2 μ s time constant was used to shape the preamplifier output pulses. The peak output signals from the shaper were digitized using a LeCroy 2282A ADC. Calibration constants and noise figures were measured for each of the 16 instrumented channels using a test pulse system. The measured noise was typically 800 (1000) electrons for the short (long) strip outputs.

4. Measurements and Results

Position detector measurements were made at the CERN SPS X1 test beam and the PS T7 test beam during September - December of 1987, using electron and muon beams with momenta between 3 and 80 GeV/c ($\Delta p/p = 0.5 - 1.0 \%$). Three position detector prototypes were filled with TMP, two of which were used for these studies. The measurements were designed to (i) study the performance of the device as a calorimeter element, and (ii) determine how well the device can measure the position of electromagnetic showers. The position detector was supported between two 1 cm thick aluminum plates, and placed in the beam so that the short (long) strips were vertical (horizontal) and measured the x (y) coordinate. The beam was at normal incidence. Figure 4 shows a schematic of the test beam set-up. A target consisting of six 2 mm thick uranium plates spaced with 3 mm air gaps was placed upstream of the front aluminum support plate of the position detector to simulate the planned position of the

detector in the upgraded UA1 calorimeter. Upstream of the target a 10 cm by 10 cm delay line wire chamber [8] with a spatial resolution of less than 200 μm was used to determine the position of incoming beam particles. Finally, scintillator and Cerenkov counters were used to trigger on incoming electrons and muons, where the muons were required to penetrate a small test Uranium-TMP calorimeter [5], an iron-scintillator hadron calorimeter [9], and 160 cm of additional iron placed behind the position detector.

i) Performance as a Calorimeter Element :

Signals from traversing electrons were observed for potential differences across the drift gap as low as four volts, corresponding to a drift field of about 32 V/cm. The drift time of free electrons was estimated from the rise time of output pulses to be greater than 45 μs . This implies a lifetime of greater than 15 μs for free electrons in the liquid. The free electron lifetime can be obtained from an analysis of the pulse shapes associated with traversing ionizing particles. The method is described in reference [10]. This pulse shape analysis yielded a lower bound on the free electron lifetime of 32 μs at 90% CL for the prototype position detector. The position detector has been designed to operate with gap potential differences of up to 3 kV. We have taken measurements with potential differences of up to 2.5 kV, corresponding to a drift field of 20 kV/cm, and a drift time of 200 ns. This drift time is very much shorter than the free electron lifetime in the liquid we have obtained, demonstrating that the cleaning and handling procedures we are using for the liquid and the position detector box are adequate. The long term stability of the free electron lifetime in the TMP contained in sealed boxes has been checked by making measurements of the lifetime periodically over a year [11]. The measurements were done using the small test Uranium-TMP calorimeter [5]. No degradation of lifetime has been observed.

Figure 5 shows the integrated charge induced on a short strip electrode, shown as a function of time after the passage of a single 70 GeV/c positron, and as a function of the drift field. The rise time of the pulse decreases with increasing field, reflecting the increasing drift velocity of the free electrons liberated in the liquid with increasing electric field. The

dependence of the drift time t_d when a potential difference of V is applied across a drift gap of d is given by :

$$t_d = d^2 / \mu V$$

where μ , the mobility of electrons in TMP, is taken to be $30 \text{ cm}^2 / \text{V sec}$ [12]. This relationship gives a good description of the observed electron drift time as a function of the gap potential difference, which has been measured for values of V up to 2.5 kV (Figure 6). The pulse shapes measured by the device are therefore well understood as a function of the drift field. To understand the pulse heights, the total charge induced on three adjacent strips has been measured as a function of the drift field for the passage of 5 GeV/c muons from the PS test beam, where the incident muons are centered on the middle strip. The results, which are shown in Figure 7, are well described by the Onsager prediction [13] up to the highest field measured (16 kV/cm).

With the uranium target placed upstream of the position detector the response of the detector has been measured as a function of the incident electron beam energy. The detector response increases monotonically with beam energy (Figure 8) and the total charge collected on the long strip electrodes is correlated with the charge collected on the short strip electrodes as expected (Figure 9). Signals of 26 (184) MIP are observed for 3 (50) GeV electron showers.

ii) Performance as a Position Measuring Device :

Figure 10 shows the profile of a 10 GeV/c electron beam at the CERN SPS measured using seven consecutive position detector strip electrodes. The position detector was placed behind the uranium target, and the delay line wire chamber was used to determine the position of the incident beam particle. Figure 10a shows the observed shower profile when the incident beam was centered on strip number 4, in figure 10b the beam is moved 1 mm to the left of the center of strip 4, and so on in 1 mm steps until in figure 10i the incident beam is centered on strip 3. The average pulse heights measured on the strips enable the beam to be located with an accuracy of better than 1 mm. The position resolution can be determined by comparing the

position of each incident electron measured using the wire chamber with the position of the resulting electron shower determined from the relative pulse heights measured on the position detector strips. We have made no attempt to refine the algorithm for determining the shower position from the position detector measurement, but have simply used the weighted average of the strip responses. The resulting distribution of the difference in the two position measurements is shown in Figure 11 for 50 GeV/c incident electrons. This distribution has an rms of 1 mm, reflecting the excellent spatial resolution obtained with the position detector for high energy electron showers. The resolution is shown as a function of electron beam momentum in Figure 12. The resolution, which improves with increasing electron momentum, is better than 2 mm rms for momenta in excess of 10 GeV/c. At low momenta the resolution degrades because shower fluctuations and noise distort the simple weighted average.

In Figure 13 the total charge induced on the sum of the eight long strips of the position detector is shown as a function of the position of the incident 10 GeV/c electron, as determined from the wire chamber measurement. This position scan goes from the center of strip 4 up to and past the point mid-way between strips 4 and 5. The response is independent of the location of the incident electron with respect to the strip center, demonstrating the uniformity of the total signal measured by the device as a function of the shower position.

Finally, having established that the position detector has excellent properties both as a calorimeter element and as a position sensitive device, we have used the detector to measure the transverse size of electromagnetic showers after the stack of six 2 mm thick uranium plates separated by 3 mm air gaps. This information is contained in Figure 10, where we see that the showers have long tails; a few percent of the shower is on strips that are 2 cm or more from the center of the shower. A more careful inspection of Figure 10 also reveals that the showers have a very sharp core at the depth where the position detector is located: most of the charge-shift between strip 4 and strip 3 comes from the three 1 mm beam-steps shown in Figures 10d, 10e, and 10f. We have measured this core, using six consecutive strips containing the shower, in the following way: we construct the difference in the total pulse heights of strips (1+2+3) and of strips (4+5+6). Then we move the beam by 1 mm across the detector and reconstruct the difference again. The difference of these differences, divided by two, is the amount of the

shower contained in a 1 mm slice. This measured transverse shower size near the core is plotted in Figure 14 for 10 and 50 GeV/c incident electrons. The width of high energy electron showers is well matched to the spatial resolution of the detector.

5. Conclusions

A full-scale prototype position detector, consisting of a sealed stainless steel box containing the room temperature liquid 2,2,4,4 Tetramethylpentane, and a highly segmented electrode structure, has been successfully built and operated in electron and muon test beams. The box, which has 90 ceramic high voltage feedthroughs and three planes of electrodes, is mechanically sound and sufficiently clean and leak tight to preserve ultra-pure TMP. The position detector has operated reliably up to a high voltage of 2.5 kV across its 1.25 mm drift gaps, corresponding to a charge collection time of 200 ns. A spatial resolution of 1 mm rms has been obtained for high energy electron showers.

6. Acknowledgements

We are thankful to the following people for their help in the preparation and collection of the data runs described here: A. Givernaud, W. Kienzle, M. Krammer, S. Lazic, R. Munoz, S. Pavlon, E. Petrolo, and D. Robinson. Acknowledgements are also due to CERN, for use of the facilities and assistance of the staff. This work was supported by the U.S. Department of Energy.

Table 1: Parameters of the position detector for the UA1 Uranium-TMP calorimeter.

Central electrodes	
Number	8
Dimensions	107 x 130 x 0.5 mm ³
Capacitance (with TMP)	378 pF each
 Short strip electrodes	
Number	58
Pitch	9.1 mm
Dimensions	213 x 7 x 0.5 mm ³
Capacitance (with TMP)	52 pF each
 Long strip electrodes	
Number	24
Pitch	9.1 mm
Dimensions	521 (two pieces: 260+261) x 7 x 0.5 mm ³
Capacitance (with TMP)	126 pF each
 Drift Gap	 1.25 mm
 Drift Field	 ≤ 20 kV/cm
 Drift Time	 ≥ 200 ns

References

- [1] E. J. N. Wilson (Editor), "Design Study of an Antiproton Collector for the Antiproton Accumulator (ACOL)", CERN / 93 - 10 (1983).
- [2] UA1 Collaboration, UA1 Proposal, CERN SPSC 78-6/P92 (1978).
- [3] UA1 Collaboration, "Design Report of a U-TMP Calorimeter for the UA1 Experiment with ACOL", UA1 TN/86-112.
- [4] M. Corden et al., Phys. Scr. 25 (1982) 5 and 11.
- [5] M. G. Albrow et al., Nucl. Instr. and Meth. A265 (1988) 303.
- [6] UA1 Collaboration, "Tests of a U-TMP Calorimeter Module", to be published.
- [7] G. Barichello et al., "A Low-noise Amplification Chain for the Vacuum Photo-Triode Read-out of the Delphi Lead Glass Calorimeter", DFPD/3/86.
- [8] A. Manarin and G. Vismara, LEP/BI-TA/Note 85-3 (1985).
- [9] M. J. Corden et al., Nucl. Instr. and Meth. A238 (1985) 273.
- [10] A. Gonidec et al., CERN preprint EP/88-36 (1988), submitted to Nucl. Instr. and Meth.
- [11] UA1 Collaboration, "Long Term Stability of U-TMP Calorimeters", CERN-EP/87-55 Addendum (1987).
- [12] T. G. Ryan and G. R. Freeman, J. Chem. Phys. 68 (11), 1978.
- [13] L. Onsager, Phys. Rev. 54 (1938) 554.

Figure Captions

- Fig. 1 Cross-section of a central calorimeter module in the upgraded UA1 detector, showing the structure of uranium plates and TMP boxes, and the location of the position detector. The preamplifiers are mounted in front of the module as indicated by the shaded area before the aluminum plate.
- Fig. 2 Schematic drawing showing the electrode structure inside the position detector box.
- Fig. 3 An assembled position detector box placed on an aluminum support plate. The feedthroughs and the TMP fill tubes can be seen.
- Fig. 4 Schematic of the test beam layout.
- Fig. 5 Integrated charge induced on a short strip electrode shown as a function of time after the passage of a single high energy electron for a drift field of (a) 2 kV/cm, (b) 8 kV/cm, and (c) 20 kV/cm.
- Fig. 6 Inverse drift time for electrons drifting across the drift gap in the TMP filled position detector box shown as a function of the gap potential difference.
- Fig. 7 Average total charge induced on 3 short strips after the passage of a 5 GeV/c muon through the middle strip, shown as a function of the drift field, and compared with the Onsager prediction.
- Fig. 8 Total charge induced on the long strips after the passage of a high energy electron, normalized to the equivalent charge induced after the passage of a minimum ionizing particle, and shown as a function of the electron beam energy.
- Fig. 9 Correlation between the observed signal on the short and long strip electrodes after the passage of 50 GeV/c electrons.
- Fig. 10 Shower profiles. The response of seven consecutive strip electrodes is shown as a function of the position of the incident 10 GeV/c electron beam. The beam position has been moved in 1 mm steps from (a) being centered on strip 4 to (i) being centered on strip 3.

- Fig. 11 Position resolution. The difference (residuals) between the hit position of 50 GeV/c incident electrons measured using a wire chamber and the position of the resulting electron shower measured with the position detector is shown.
- Fig. 12 Position resolution shown as a function of electron beam momentum.
- Fig. 13 Uniformity of the position detector response. The total charge induced on the position detector long strip electrodes, relative to the charge induced after the passage of a minimum ionizing particle, is shown as a function of the position of the incident 10 GeV/c electron.
- Fig. 14 Transverse electron shower size measured with the position detector after 3.75 radiation lengths of uranium (six 2 mm thick plates separated by 3 mm air gaps).

FIG. 1

FIG. 2

FIG. 3

FIG. 4

a)

b)

c)

FIG. 5

FIG. 6

FIG. 7

FIG. 8

FIG. 9

FIG. 10

FIG. 11

FIG.12

FIG. 13

FIG. 14