NUCLEAR INSTRUMENTS AND METHODS 163 (1979) 77-81; © NORTH-HOLLAND PUBLISHING CO.

ELECTRON ENERGY AND POSITION MEASUREMENT USING LEAD–SCINTILLATOR CALORIMETERS WITH A NEW LIGHT COLLECTION SYSTEM

W. HOFMANN, J. SPENGLER, D. WEGENER

Institut für Physik, Universität Dortmund, Dortmund, Germany

A. KROLZIG, W. SCHMIDT-PARZEFALL

DESY, Hamburg, Germany

and

K. R. SCHUBERT

Institut für Hochenergiephysik, Universität Heidelberg, Heidelberg, Germany

Received 23 November 1978 and in revised form 15 March 1979

A lead – scintillator shower counter using a fluorescent radiation converter for collecting scintillation light is described. For primary electrons of 1 GeV an energy resolution of 6–7.5% rms was obtained. With a 3×3 matrix of such calorimeter modules, the uniformity of energy response and the spatial resolution have been measured. From the energy sharing between the nine cells, the electron impact position was reconstructed with an accuracy of 10–15 mm rms.

1. Introduction

The use of sampling scintillation counters to measure the energy of electrons and photons is well established. In order to obtain a good energy and impact position resolution in a lead scintillator array it is important to incorporate both fine sampling and extensive segmentation. Normally, these conditions imply extreme complications with respect to the light guide system.

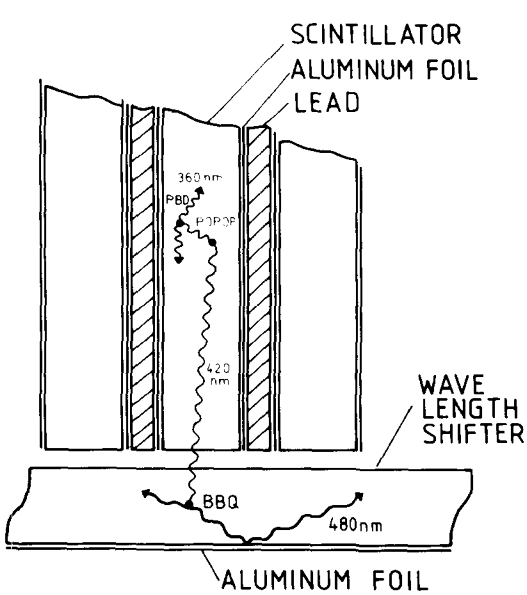

Fig. 1. Collection of scintillation light with a wavelength-shifter bar; PBD: primary fluor emitting UV light, POPOP: wavelength shifter UV – blue, BBQ: wavelength shifter blue – green.

One possibility to circumvent these problems is based on the use of fluorescent radiation converters for the collection of scintillation light[1–4]). This technique was first applied to calorimetry by Atwood et al.[5]) and by Eckardt et al.[6]).

The method is illustrated in fig. 1. One side of the calorimeter, consisting of a stack of alternating lead and scintillator plates, is covered with a lucite light guide doped with the fluorescent material BBQ. The scintillator emits light in the UV range. After a few mm, this light is absorbed by a further scintillating material (POPOP), and reemitted at $\lambda \sim 420$ nm. This initial wavelenght shift is necessary to obtain a large attenuation length in the scintillator. The blue light leaves the scintillator sheet at its lower edge, crosses a small air gap and enters the BBQ/lucite light guide. It is then absorbed by the BBQ and reemitted isotropically as green light of $\lambda \sim 480$ nm. Roughly one half of this emitted light lies within the total reflection angle of the light guide and is transported to a phototube. Further details of the method are discussed in refs. 3–6.

In this paper, we report on tests of such a shower counter optimized for energy and position measurement of electrons and photons.

2. The electron calorimeter

The test setup consisted of nine identical calorimeter modules. Each of these modules contained a stack made of alternating layers of

$0.5 \times 10 \times 10\ cm^3$ plastic scintillator and $0.1 \times 10 \times 10\ cm^3$ lead plates, 130 layers in all. The overall length of one module was 40 cm corresponding to 12.5 radiation lengths. This configuration was chosen for two reasons. First, the fine sampling of 1 mm lead guarantees a high energy resolution; second the counter has a rather low density $\langle \rho \rangle \simeq 2.9\ g/cm^2$ and therefore a comparably large mean radiation length $\langle \lambda_{rad} \rangle \simeq 3.1$ cm. As the rms lateral spread of electromagnetic cascades is of the order of 1 radiation length, at least 10–15% of the shower energy leaks out of the sides of one module into the neighbouring ones. Using the energy sharing between the calorimeter modules, the shower center can be determined with an error which is small compared to the width of one module (10 cm).

The lead–scintillator stacks were placed on sheets of wavelength-shifting plastic with dimensions $0.5 \times 10 \times 40\ cm^3$. The wavelength shifters were attached to (Valvo, XP 2008) phototubes using standard adiabatic light guides. A nylon thread of 0.3 mm diameter served to separate the lead absorber and scintillator sheets from the wavelength shifter bar. In this way total reflection was maintained. Each of the scintillator slabs was wrapped in aluminium foil on both faces; the wavelength shifter was also backed with an aluminium foil.

A 1 mm steel housing ensured mechanical stability. A schematic view of parts of one module is shown in fig. 2. The modules were arranged in a 3×3 matrix and tested in an external electron beam of the DESY synchrotron. The energy range covered by this test was 0.5–1.5 GeV. The lateral width of the beam was roughly 0.2 cm rms, its energy spread was negligible compared to the measured resolution of the shower counters.

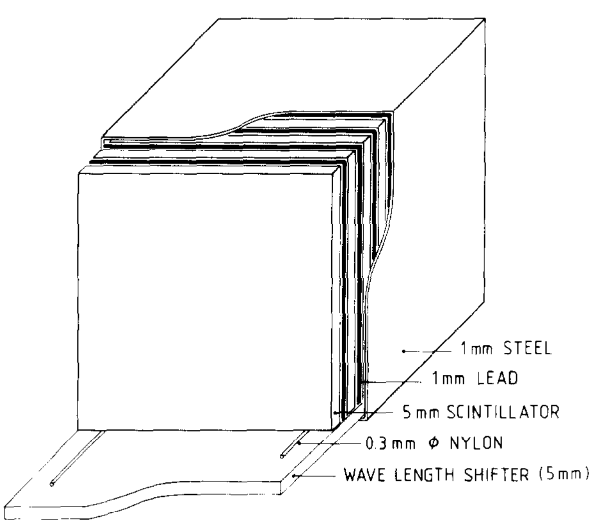

Fig. 2. Design of test counters.

3. Test results

The rms energy resolution of a typical calorimeter module is shown in fig. 3 for energies of 0.5, 1.0 and 1.5 GeV (full dots). The resolution is described by

$$\frac{\sigma_E}{E} = \frac{7.5\%}{\sqrt{E}}\ (E \text{ in GeV}).$$

The resolution obtained with the best module under optimal conditions, $\sigma_E \simeq 6\%$ at 1 GeV, is also shown in fig. 3.

For comparison, typical resolution curves of lead glass Cherenkov counters[7,8]) as well as the best values reported for liquid argon calorimeters[9]), $\sigma_E = 7\%/\sqrt{E}$, are included.

The resolution of the test counters is about the same as that of a similar liquid argon/lead stack, indicating that the resolution is not limited by photoelectron statistics. This is confirmed by studies with minimum ionizing cosmic particles, the line width of which is given by a convolution of photoelectron statistics and known Landau fluctuations. From the cosmic ray test, the photo electron

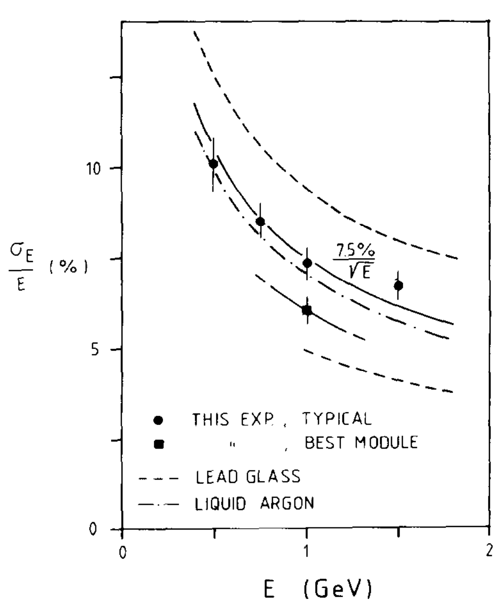

Fig. 3. Energy resolution of test counters compared with the average resolution of a typical lead–glass array[7]), an optimized limited area of lead–glass blocks[8]) (upper resp. lower dashed line) and a large liquid argon calorimeter[9]) (dashed–dotted line).

yield was estimated to be of the order of 1 photoelectron per MeV incident energy.

To determine the uniformity of the response and the spatial resolution, each counter was calibrated separately with 1 GeV electrons, and the electron beam was scanned horizontally over the counter matrix shown in fig. 4. The step width was 1 cm, the electron energy was fixed at 1 GeV. In the first run, the electron impact direction was chosen orthogonal to the counter front face.

The energy distribution between neighbouring modules is displayed in fig. 5. The quantity plotted is the fraction of energy deposited in module 3 for an electron beam hitting module 2 (see fig. 4) at a distance x from the edge of module 3. The curve can be parametrized by an $e^{-x/1.96[\mathrm{cm}]}$ dependence, in good agreement with the rough expection $e^{-x/\lambda_{\mathrm{rad}}}$. By inverting the characteristic shown in fig. 5, the horizontal coordinate of the electron impact position can be calculated. The result is shown in fig. 6 averaged over many showers per point. In figs. 6 and 7, x is redefined, $x=0$ now means the centre of cell 2.

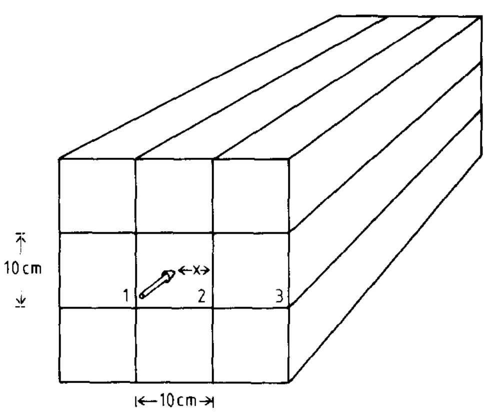

Fig. 4. Configuration of test counters to measure uniformity and position resolution.

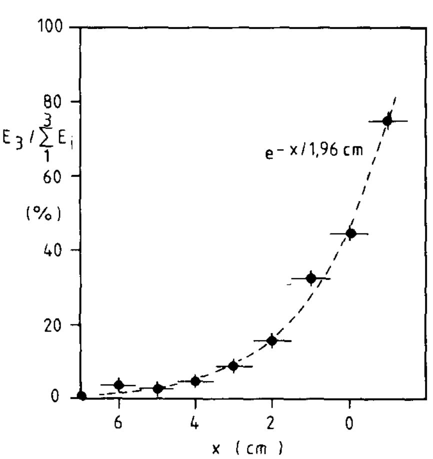

Fig. 5. Fraction of energy deposited in module 3 for a particle beam hitting module 2 (see fig. 4). x is the distance between the impact position and the edge of module 3.

The performance of the calorimeter is displayed in fig. 7, where the visible energy summed over all counters, the energy resolution and the spatial resolution are given for different beam positions x. In the central 8 cm of a module, the visible energy is constant and the energy resolution is close to its optimum value for central impact. At the edges of the module however, a loss of 20% of the energy and a corresponding decrease in resolution is observed, which can be traced to a dead space of roughly 5 mm between the sensitive regions of two neighbouring modules. The present design was not optimized in this respect; with a suitable design the gap could be reduced to 1 mm and its influence should then be negligible. Similar effects were observed when the beam crossed the gap caused by the wavelength shifters at the top and bottom, respectively, of the counters.

The electron position resolution is about 15 mm rms at the center of a module and improves to 10 mm rms at the edge. The same tests were repeated in a second run with an electron impact angle of 20° with respect to the normal to the counter front side, as indicated at the top of fig. 8.

The electron beam entered module 1, whose centre is now at $x=0$, the induced shower traversed module 2 and ended in 3. The results for visible energy, energy and position resolution are given in fig. 8. For 20° impact, no deviations from uniformity are observed; the effects of the intermo-

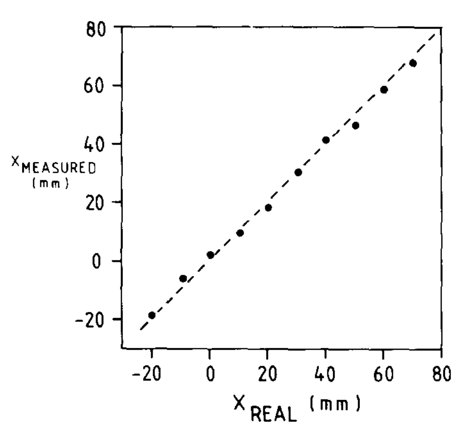

Fig. 6. Measured vs real impact position averaged over many cascades. $x=0$ is the centre of module 2.

dule gap are smeared out resulting in a slightly worsened energy resolution. As the shower energy is now distributed over 3 modules, the shower center can be reconstructed with an improved accuracy of roughly 10 mm rms.

4. Conclusion

The new technique of scintillation light collection

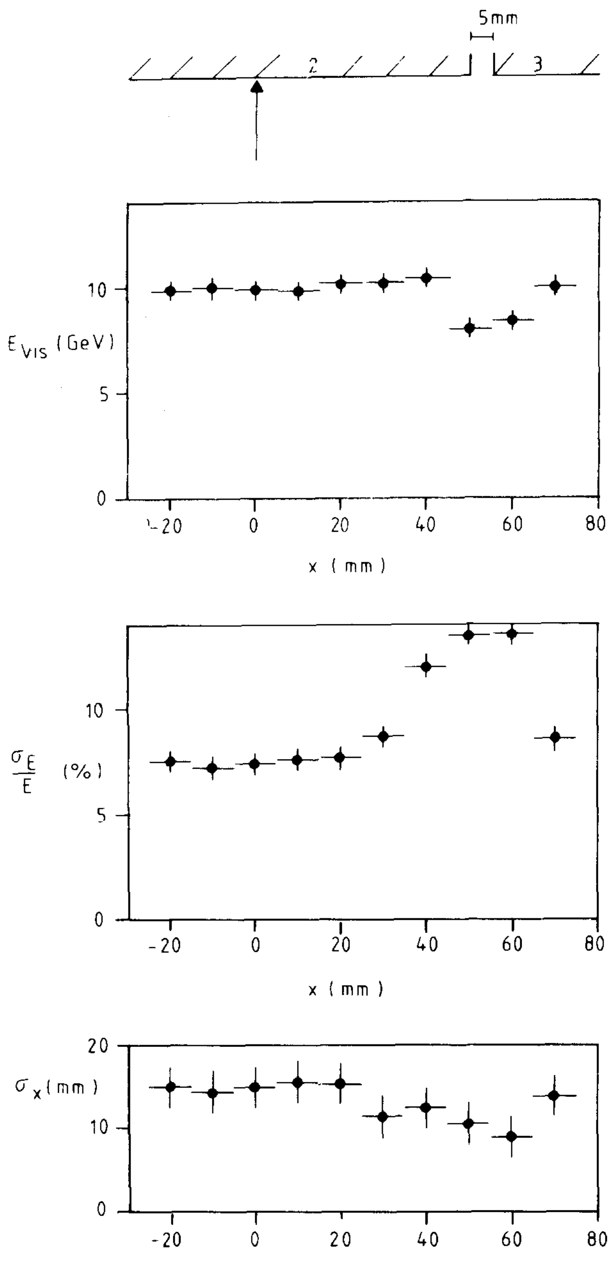

Fig. 7. Visible energy, energy resolution and spatial resolution as a function of the impact position x. $x = 0$ corresponds to the centre of module 2.

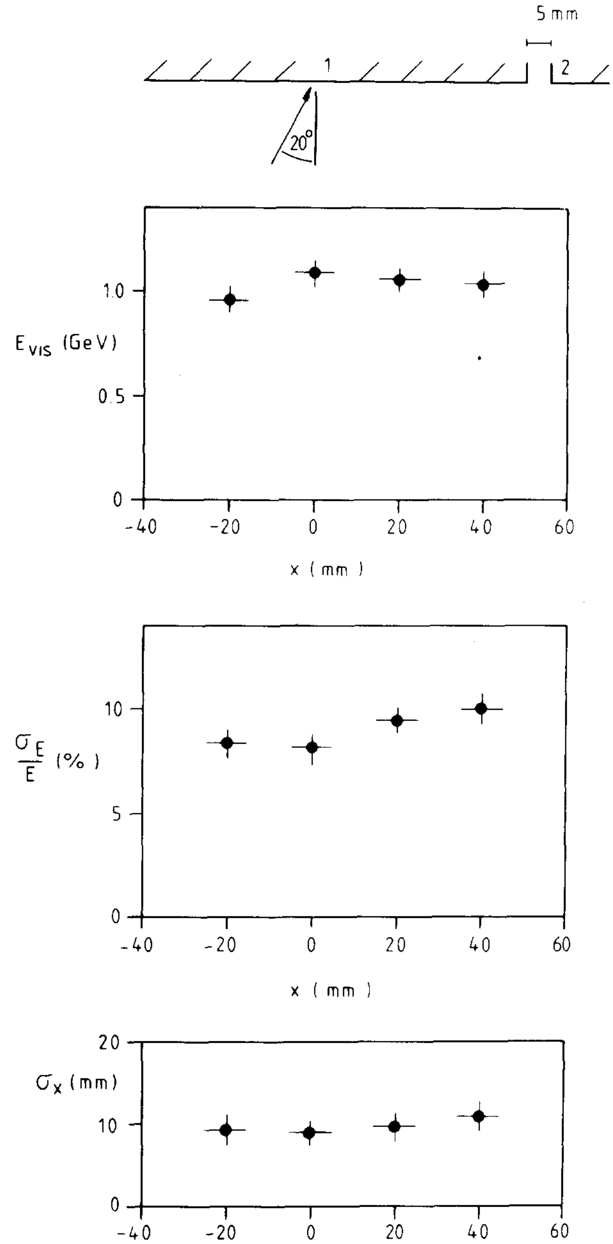

Fig. 8. As fig. 7, beam inclined by 20°. The electromagnetic cascade starts in module 1 and ends in module 3; $x = 0$ is the centre of module 1.

via fluorescent radiation converters allows the construction of segmented lead-scintillator shower counters with high energy and position resolution. As the dead space from the support and read out can be reduced to ~5% of the total, this type of calorimeter is well suited for application in 4π detectors at storage rings; it offers a performance similar to liquid argon calorimeters at a greatly reduced cost.

We acknowledge the help of W. Reinsch during the setup of the test. We thank our technicians and the workshops at DESY and Dortmund for their skilfull work. This work was supported by a grant of the Bundesministerium für Forschung und Technologie.

References

1) W. A. Shurcliff, J. Opt. Soc. Am. **41** (1951) 209.
2) R. C. Garwin, Rev. Sci. Instr. **31** (1960) 1010.
3) G. Keil, Nucl. Instr. and Meth. **87** (1970) 111.
4) A. Barish et al., CALT 68-623 (1977).
5) W. B. Atwood et al., SLAC-TN-76-7.
6) V. Eckardt et al., MPI-PAE/Exp. El 70 (1978).
7) D. P. Barber et al., DL/P273 Experimental (1977).
8) J. A. Appel et al., Nucl. Instr. and Meth. **127** (1975) 495.
9) F. Mönnig (CELLO Collab.), Frühjahrstagung des Fachausschusses Teilchenphysik der DPG, Heidelberg (1978).