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SHOWER MAXIMUM DETECTOR DESIGN AND INSTALLATION

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A Shower Maximum Detector design compatible with the cast-lead EM calorimeter design is presented. Four separate SM units are necessary for each 4x4-tower SM slot. The SM strips in each unit are glued to a 2-mm cover sheet, with notches to facilitate fiber routing. The SM units can be assembled and tested at Saclay, before shipment. The SM units can be inserted in the SM slots in the cast-lead EMC without feeding fibers through the slot.

1. Introduction

A review of the SDC EM calorimeter design was held at SSCL in June 1992. The committee was to review the cast-lead and stacked-lead designs for the EMC and make a recommendation. Compatability with the requirements of the Shower Maximum Detector was one of the explicit criteria for this decision.

The review committee found that there were difficulties with both designs. The main problems arose from the special conditions imposed by the installation of the Shower Max Detector. Recent studies on the cast-lead design have shown that the Shower-Max slot near $\eta = 1.4$ is deformed by about 5 mm for the wedge in the 12 o'clock position. For the stacked-lead design, the problem is the non-uniform loading of the Shower-Max tiles due to the notches required in the support plates to provide sufficient space for the fiber routing.

The review committee felt that these difficulties could be overcome, and that either design could be made to work. Under these conditions, the committee felt that there was insufficient reason to switch from the current cast-lead baseline design to the stacked-lead design. The cast-lead advocates were asked to address certain design questions, mainly concerning the deformation of the SM slot and the response of bevelled tiles, and to report back at the August SDC meeting.

The present note proposes a Shower Maximum Detector design compatible with the 26-mm SM slot in the cast-lead design (20 mm for the SMD and 6 mm for the EMC sigma-tiles). It is hoped that the SM units can be assembled and tested at Saclay before shipment to Fermilab. The SM units (four units per SM slot) can be installed without feeding fibers through the SM slot.

2. Shower Max Design

2.1. General layout and assembly

The cast-lead barrel EMC is shown in Figure 1. The full EMC wedges cover half the length of the barrel, and 1/32nd of the azimuth. There are 4x28 EM towers in a wedge. There are bulkheads separating the towers every two towers ($\Delta\eta$ of 0.10) except at shower max, where every other bulkhead is removed. Thus, the Shower Max slot contains 4x4 EM towers (0.20x0.20). To allow room for the SM strips, two lead plates are removed at shower max, providing a slot 26 mm deep (6 mm for the normal EMC sigma tiles, and 20 mm for the SMD tiles).

Figure 2 shows the SM η- and ϕ-strips for a single 4x4-tower Shower Max slot. The fiber routing across the surface of the SM tiles is shown. The SM strip width is .05/8 units of η or ϕ and the length is 0.10 units. (The electronic channels gang two of the physical strips together to form logical units 0.20 units long.) The fibers exit the SM slot with a 90-degree turn into a 1.5-mm deep fiber slot in the ϕ-crack. All fiber routing must be accomplished with fiber turning-radii of at least 30 mm. (Figure 3 shows the loss of transmission as a function of the bending radius of the fibers.)

The external fiber routing implied by Figure 2 is shown in Figure 4 for fibers from a EMC section between $\eta = 0$ and $\eta = 0.2$. The SM η-fibers exit the SM slot downstream of the ϕ-fibers. The two groups of η-fibers exit in the same plane at opposite ends of the four-tower wide SM slot. The two groups of ϕ-fibers exit in separate planes, toward the center of the SM slot. All fibers from the normal EMC sigma tiles exit into the slot above their particular EMC tower; fibers from neighboring EMC towers exit symmetrically in order to leave more room for the SM fiber routing. The total number of fibers above each tower is 2x2 MG fibers + 2x29 EMC fibers + 16 SM fibers = 78 fibers; The fiber-routing slot is about 120 mm wide at the downstream end of the EMC.

The external fiber routing for a section from $\eta = 1.2$ to $\eta = 1.4$ is shown in Figure 5. The SM slot in this section is twice as long as the SM slot in the section between $\eta = 0$ and $\eta = 0.2$, but the space available for the fiber routing along the EMC is roughly the same as that at $\eta = 0$. Furthermore, some of the fibers must make a 150-degree turn into the fiber slot, instead of the 90-degree turn required at $\eta = 0$. On the other hand, there are fewer EMC fibers at large η than at $\eta = 0$. Figure 5 shows that there is space available if more fibers are needed.

2.2. Fabrication of Shower Max Units

The Shower Max fabrication described here permits the assembly of the EM calorimeter without feeding any fibers through the SM slot. This design requires four SM units for each 4x4-tower SM slot. The insertion of these SM units into the SM slot is shown schematically in Figure 6. The fabrication of the SM η-units and ϕ-units is shown in Figures 7 and 8 respectively.

The η-units (Fig. 7) consist of 32 η-strips 4-mm thick, a fiber- routing plate 2-mm thick, and a cover plate (plastic or aluminium) 2-mm thick. These elements are glued together to form a solid unit. (Using a box to hold the SM strips inevitably increases the size of the η and ϕ cracks.) The SM η-fibers are routed to the opposite side of the SM slot. To maintain a minimum depth for the SM slot, while allowing

the fibers to exit the SM strip in a straight line, the two η-units are constructed with a 2-mm overlap. As shown in Figure 6, these η-units are inserted in the SM slot first, so there is ample room to slide the two units into their overlapping positions.

The SM ϕ-units are shown in Figure 8. Each of these units contains two groups of 16 SM strips, two fiber-routing plates, and two cover plates, all glued together to form a solid unit. This time the two groups of SM strips are in two different planes, offset by 2 mm. The SM ϕ-fibers are routed to the same side of the SM slot, so the two ϕ-units can be inserted in the same plane, and butted up against each other, as shown in Figure 6.

2.3. Fiber routing

Notches are cut in the fiber-routing plates and in the cover plates to leave room for fiber routing out of the plane. These notches are shown in Figures 7 and 8. They are required because of the large number of fibers in each of the fiber bundles. A single fiber can make a 90-degree turn from the vertical plane to the horizontal plane as long as 60 mm (twice the minimal turning-radius) are available tangent to the scintillator slot. Multiple fibers require much more room. The minimal pitch for succeeding 1-mm diameter fibers with a 30-mm turning radius is 8 mm (see Fig. 9). A bundle of 16 fibers requires 158 mm (16*8 + 30) to make the 90-degree turn from the vertical plane to the horizontal plane, starting from the position where the first fiber leaves the SM slot. At $\eta = 0$, the SM slot width is 109 mm, and there are 16 EMC fibers upstream of Shower Max, so the space available for the SM fiber bundle is at most 93 mm (109 - 16*1). The tangential space required can be reduced by allowing some of the fibers to move to a different vertical plane.

The radial space available for SM fiber routing is illustrated in Figure 10. Fibers exit the SM slot where there are notches in the fiber-routing plates. The notches in the cover plates allow extra room for fiber routing. The fiber-routing plates and the cover plates are both 2-mm thick, so 4 mm of radial space is available for each of the 16-fiber SM bundles. Fiber-routing studies at Saclay using a wooden EMC model confirm that all the turning radii can be maintained below the 30-mm limit.

3. Photostatistics

The e/π and π^0/γ separation power depends on the energy and the position resolution of the SMD. The resolution is influenced by the light yield of showers traversing the scintillator strips.

Experimentally, the light yield in a scintillator is expressed as the average number of "photoelectrons per minimum ionizing particles" (p.e./m.i.p.). The measurements are made with β-sources or cosmic rays. For the SMD, measurements have been made with 4mm thick scintillator strips coupled to wave-length-shifting (WLS) fibers spliced to clear fibers and read out by a photomultiplier tube. In the best configuration, the measured light yield of the SMD strips is 1.3 p.e./m.i.p. (section 4).

A GEANT Monte Carlo simulation of electromagnetic showers using the precise geometry and characteristics of the EM Calorimeter and the SMD has been performed. Showers from electrons of 10 and 20 GeV have been followed through the SDC detector and their energy deposition in the 4 mm thick

SM scintillator strips has been recorded. The distributions reflect the intrinsic fluctuations in shower development which contribute to the stochastic term in the energy resolution. The energy deposit can be expressed in numbers of equivalent m.i.p.'s . From this number and from the light yield, the average number of photoelectrons produced by the shower in the SM strip is determined. To reflect the statistical nature of the photoelectric conversion in the PMT, the number of photoelectrons for a given energy deposit is taken from a Poisson distribution around the average value. For very low photostatistics, the width of the "measured" energy deposit distributions increases.

3.1. Energy Resolution

Our results show that photostatistics do not make a significant contribution to the energy resolution for light yields above 1 p.e./m.i.p. (Fig. 11). As a practical illustration, we can calculate the light yield obtained with the SMD in the 1991 beam test at FNAL: the measured energy resolution was 19.6% r.m.s. at 35 GeV [1]. According to the Monte Carlo simulation, the intrinsic fluctuations in shower development produce a resolution of 18%. Deconvoluting these two contributions, we find a contribution due to photostatistics of 7.8%, corresponding to 0.6 p.e./m.i.p. .

3.2. Position Resolution

An electromagnetic shower deposits most of its energy in three adjacent SM strips. By using the relative pulse heights in these strips it is possible to improve the nominal resolution of $w/\sqrt{12}$, where w is the width of the strips. Reduced resolution on the energy deposit in adjacent strips will decrease the precision of the position measurement. Figure 12 shows the resolution on the position measurement for 10 and 20 GeV electrons, for photostatistics ranging from 0.2 to 4 p.e./m.i.p. An average light yield of 1 p.e./m.i.p. is sufficient for good position resolution.

More details can be found in a forthcoming SDC note [2]

4. Light yield in Shower Maximum strips

Absolute light yields of SM strips have been measured using a β source and cosmic rays. The strip is read out by wave length shifting fiber spliced to a clear fiber. The fiber is connected to a PMT equiped with a standard bialkali photocathode. The spectrum of light reaching the PMT has been measured and convoluted with the quantum efficiency of the photocathode; the average quantum efficiency is 12.5%. The pulse height of the PMT is analysed by an ADC gated by the signal from the trigger counter. Figure 13 shows the pulse height distribution from a SM strip with an average light yield of 1.6 p.e./m.i.p. . The standard strip is made of SCSN-81 scintillator and is 20cm long, 1.3cm wide and 4mm thick. The WLS fiber (BCF91A from BICRON) is 1mm in diameter, and 23 cm long; it is spliced to a 4m long clear fiber which has a second splice after 2m. All faces are polished and the strip is wrapped in white reflective plastic. The end of the WLS fiber is polished, and the wrapping material acts as a reflector. Figure 14 shows the light yield of such a strip as a function of the length of the clear fiber. The data

point at 4 m is close to the SDC configuration which has a connector after 2 m of clear fiber, followed by an additional 1-2 m of clear fiber.

The measured light yield is 1.3 p.e./m.i.p. in this realistic configuration. This light yield does not compromise the SMD resolution in energy and position (section 3).

If the strip is painted with white paint (BC-620 from BICRON) instead of being wrapped, the light yield is reduced to 0.8 p.e./m.i.p.. We hope we can improve this last result in order to use the assembly technique described in this note. (The light yield is increased by a factor ~ 1.8 if the fiber is glued into the groove, to 2.3 and 1.4 p.e./m.i.p. for wrapped and painted strips respectively).

More details on light yield measurements can be found in a forthcoming SDC note [3].

References

[1] SDC-92-343 : Performance of a Prototype Shower Maximum Detector for the SDC.

[2] Results on Simulations of the SDC Shower Maximum Detector , SDC note to be submitted.

[3] Measurements of light yields and radiation damage in the SDC Shower Maximum detector, SDC note to be submitted.

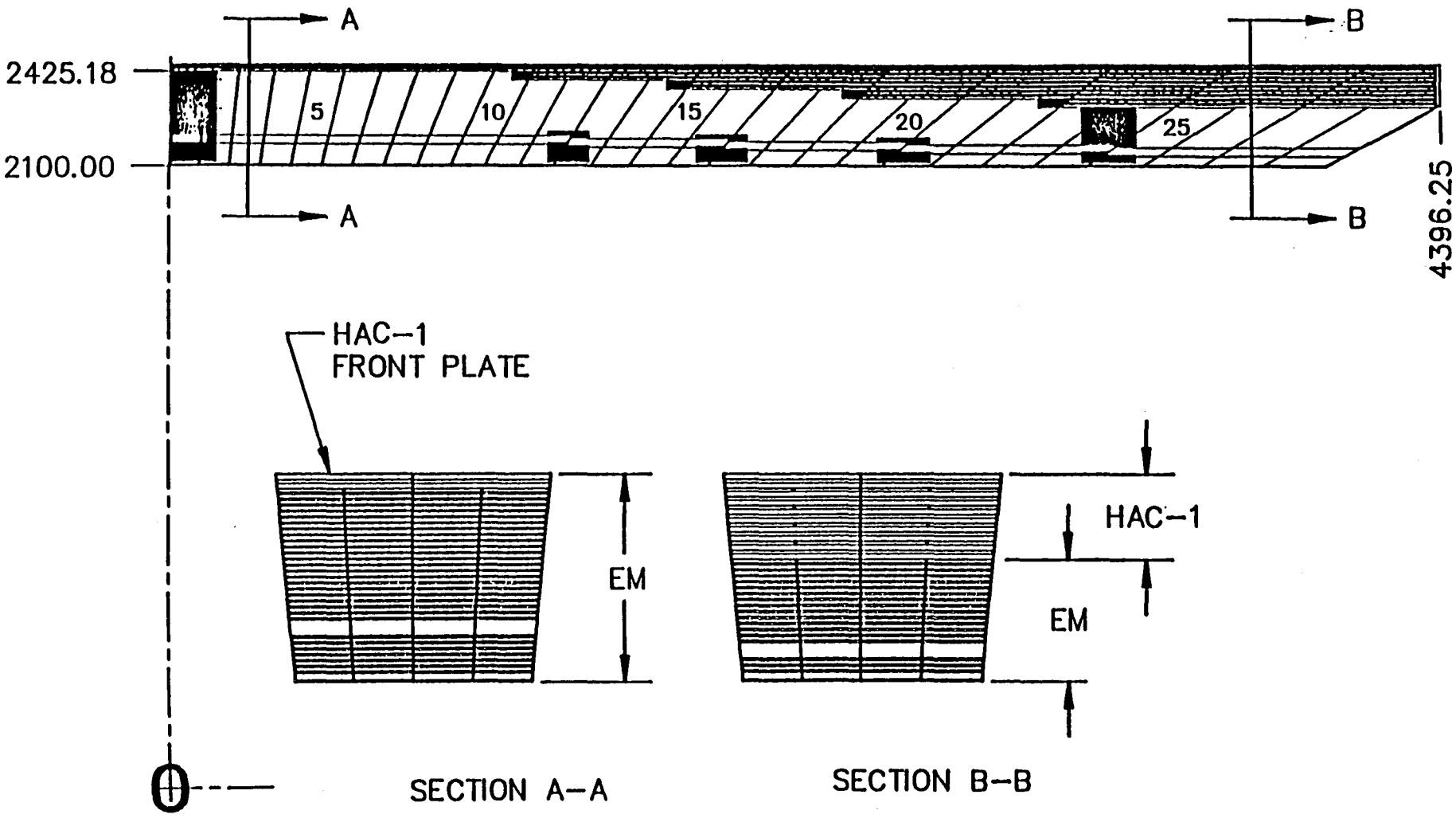

Fig. 1. Cast-lead barrel EM calorimeter (ANL design).

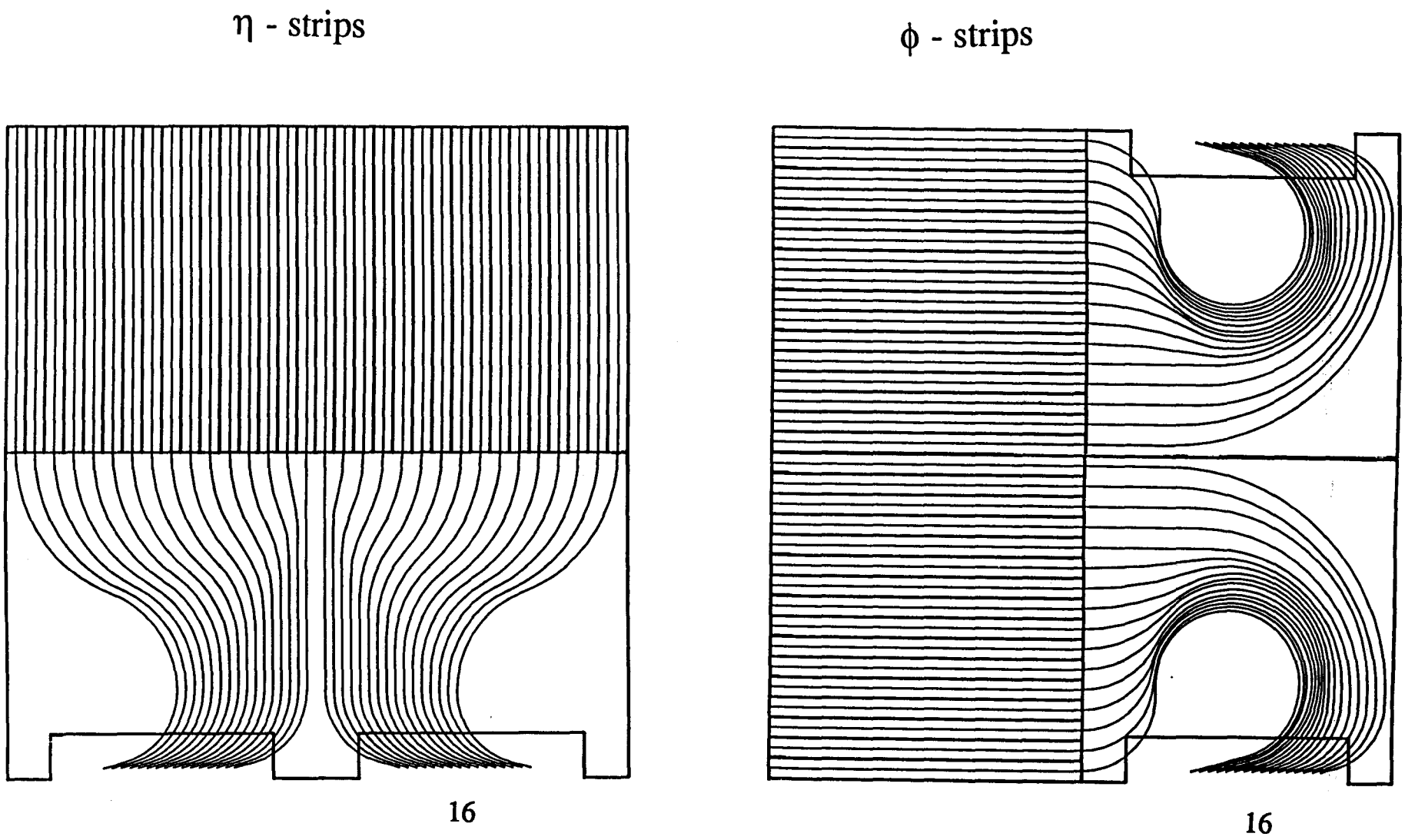

Fig. 2. Fiber routing inside SM slot.

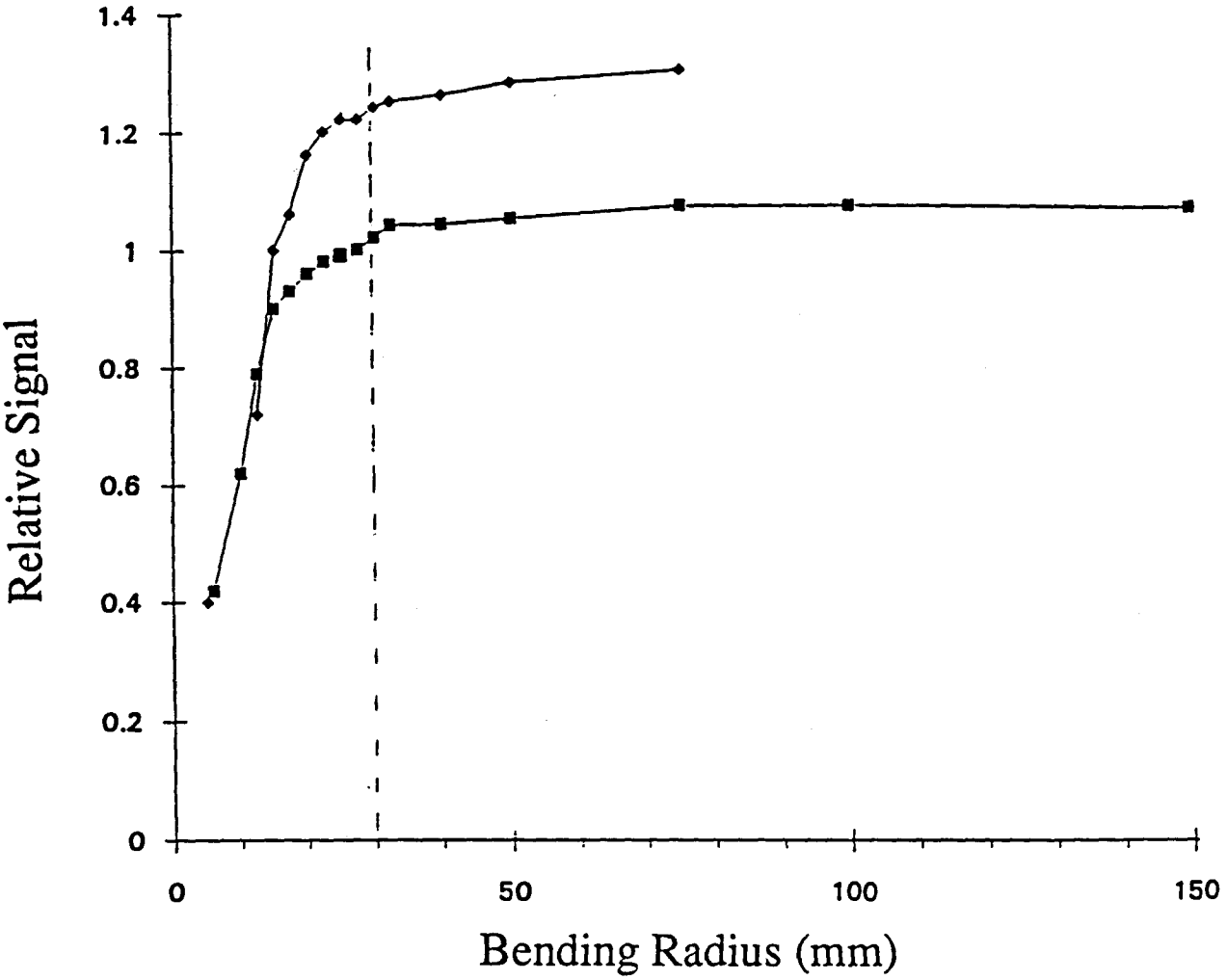

Fig. 3. Transmission as a function of fiber turning-radius.

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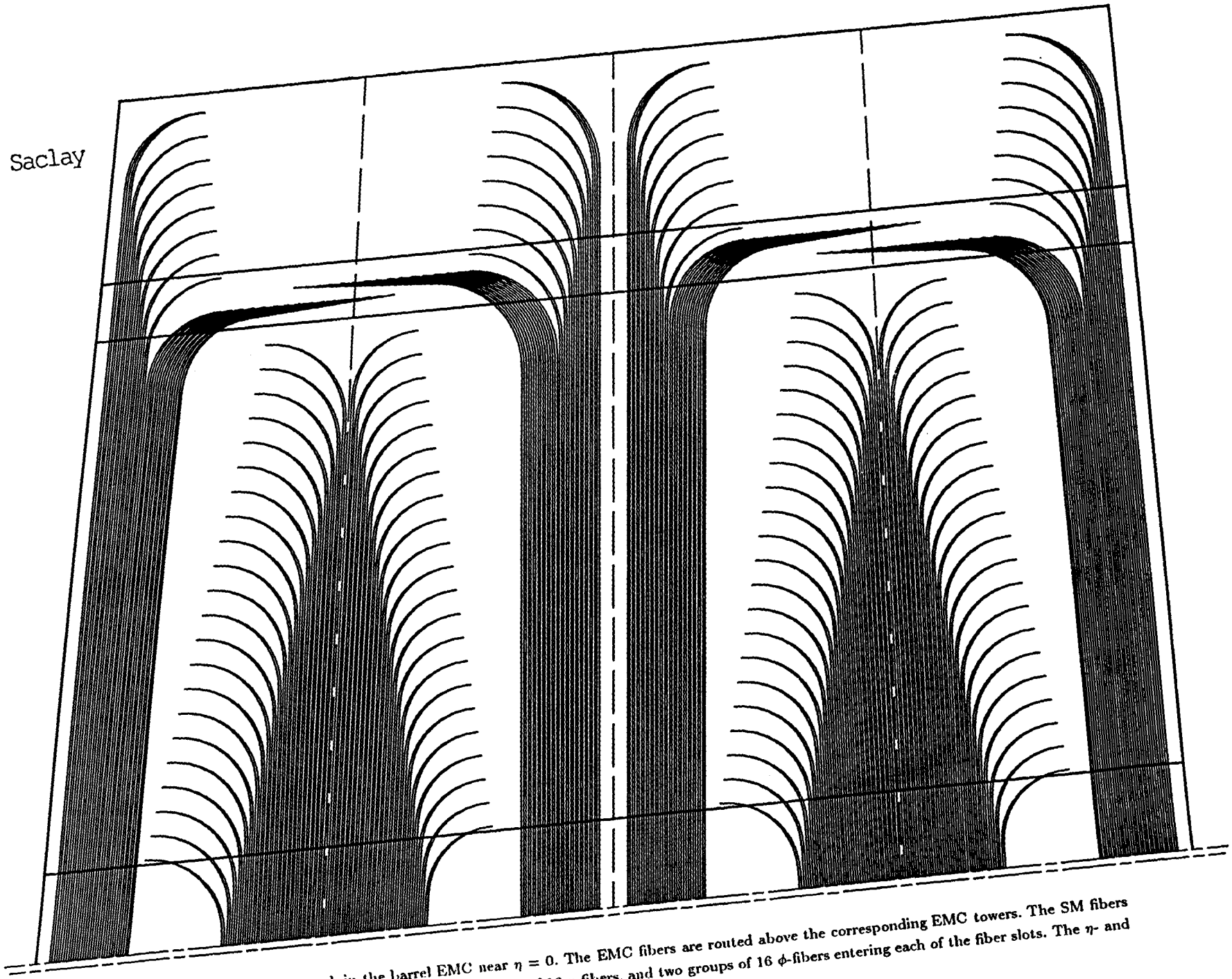


Fig. 4. Fiber routing along a ϕ-crack in the barrel EMC near $\eta = 0$. The EMC fibers are routed above the corresponding EMC towers. The SM fibers are routed symetrically above the 4x4 SM slot, with two groups of 16 η-fibers, and two groups of 16 ϕ-fibers entering each of the fiber slots. The η- and ϕ-fibers exit at different radial positions in the SM slot.

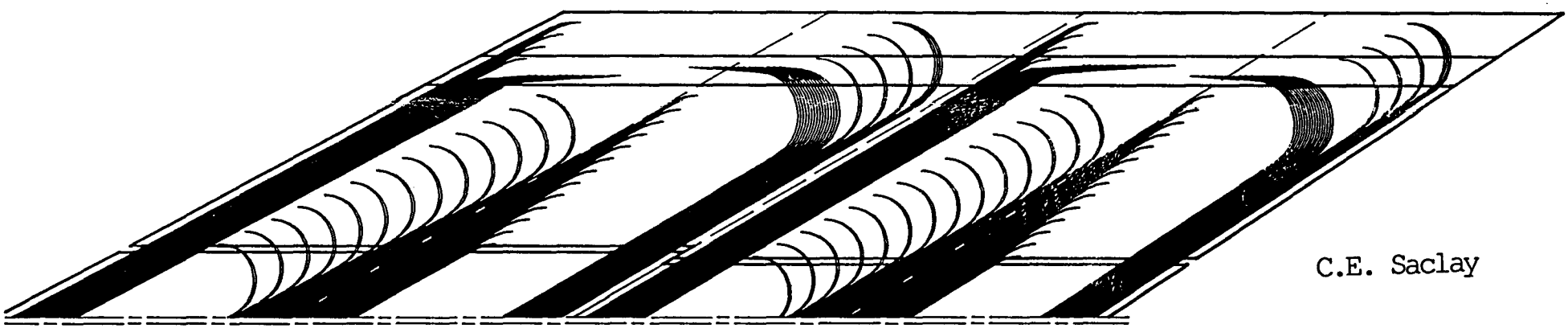


Fig. 5. Fiber routing along a ϕ-crack near the end of the barrel EMC (η between 1.2 and 1.4).

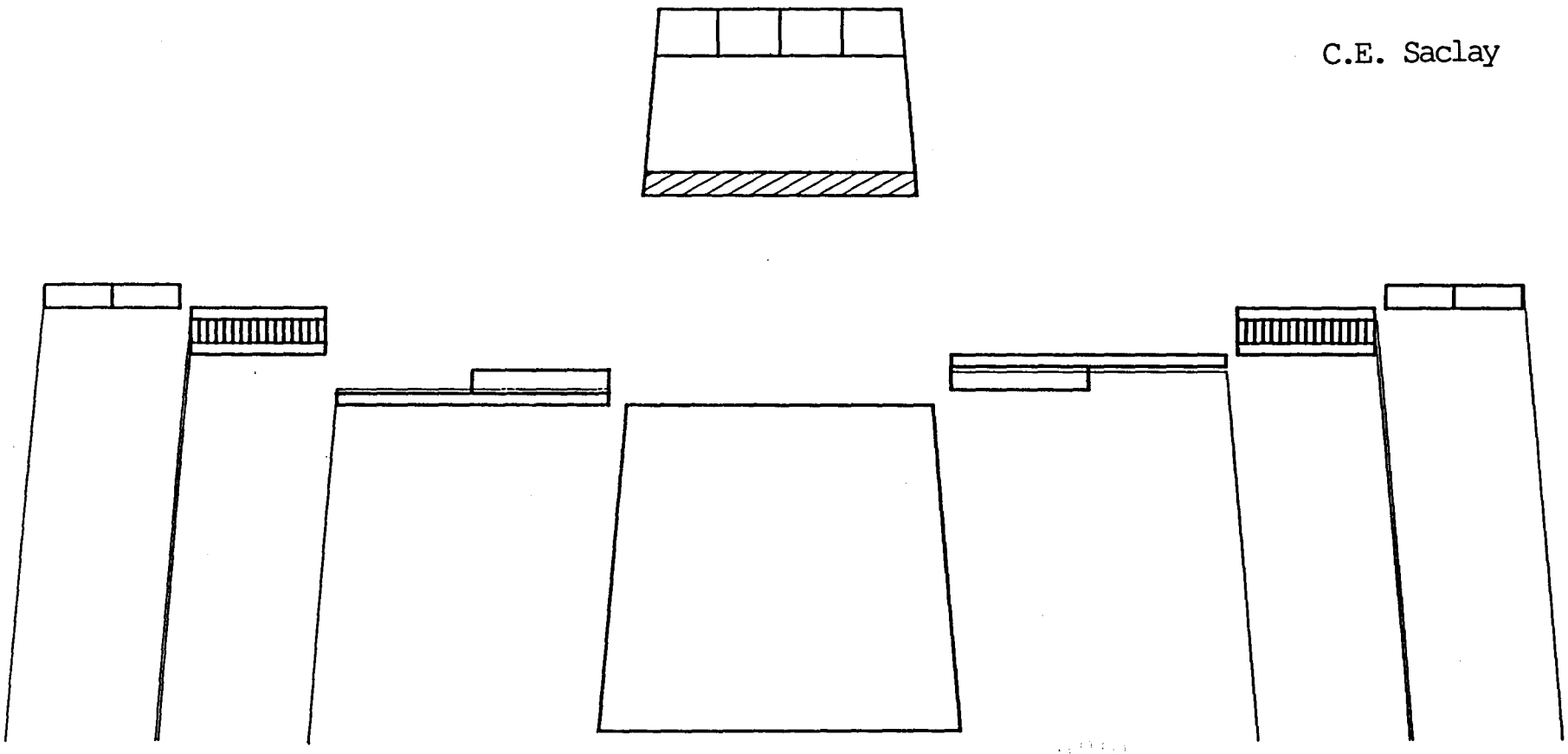


Fig. 6. Insertion of SM units into the SM slot during assembly. First, the two η-units are inserted and locked into their overlapping positions. Then the two ϕ-units are inserted and butted-up against each other. Finally, the two units containing the normal EMC sigma-tiles are inserted.

C.E. Saclay

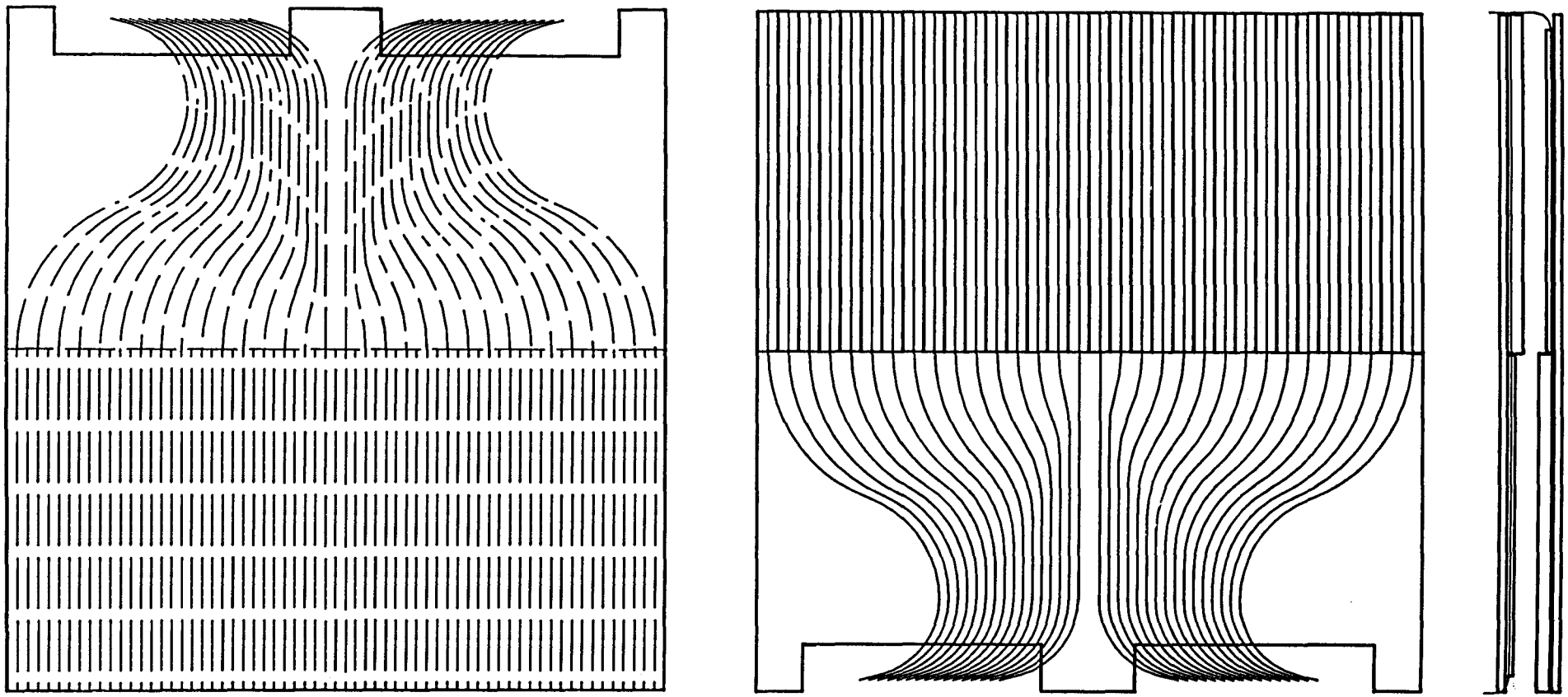


Fig. 7. Fabrication of a SM unit for η-strips.

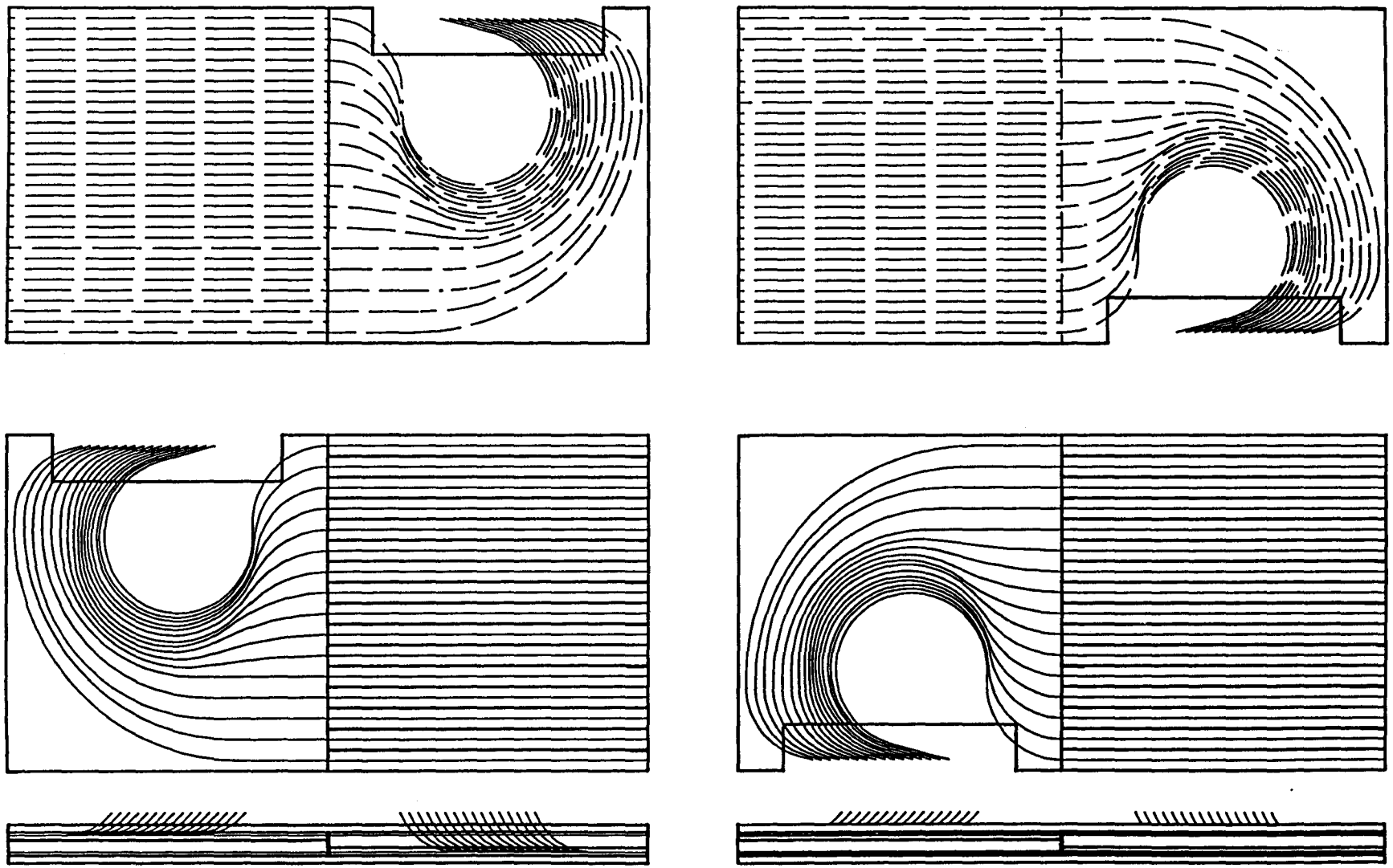


Fig. 8. Fabrication of a SM unit for ϕ-strips.

Fiber Routing in 3D

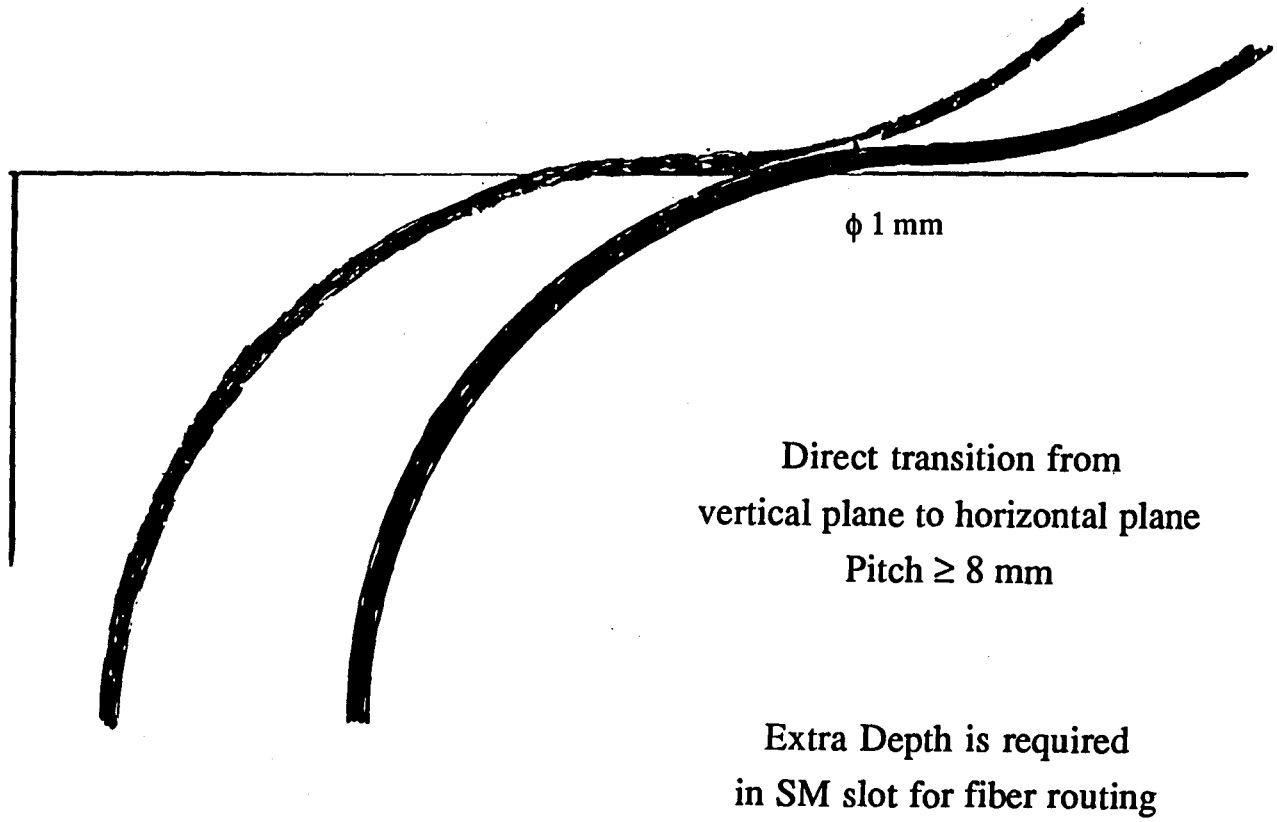


Fig. 9. Minimum pitch for a 90-degree trun from the vertical plane to the horizontal plane.

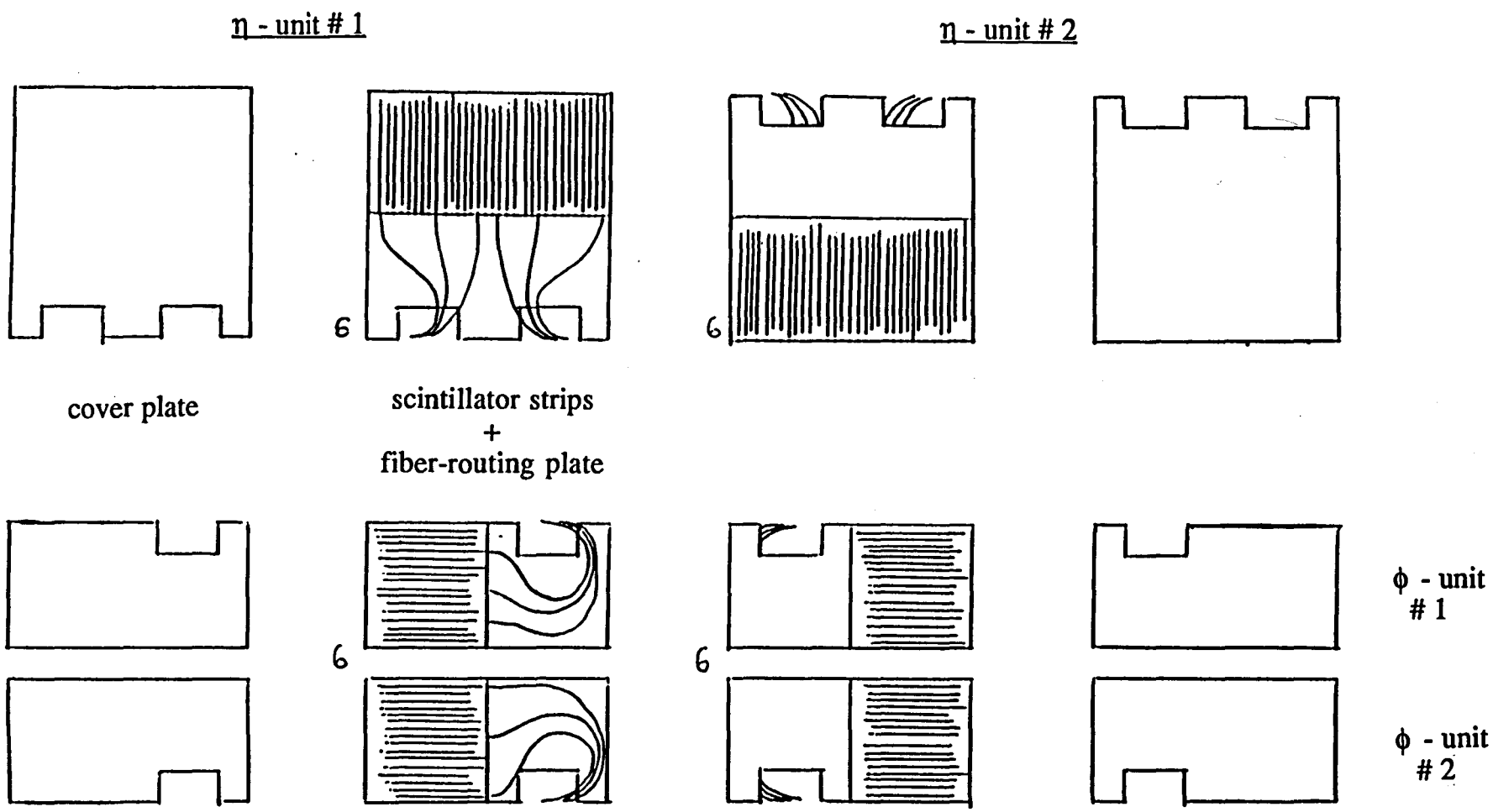
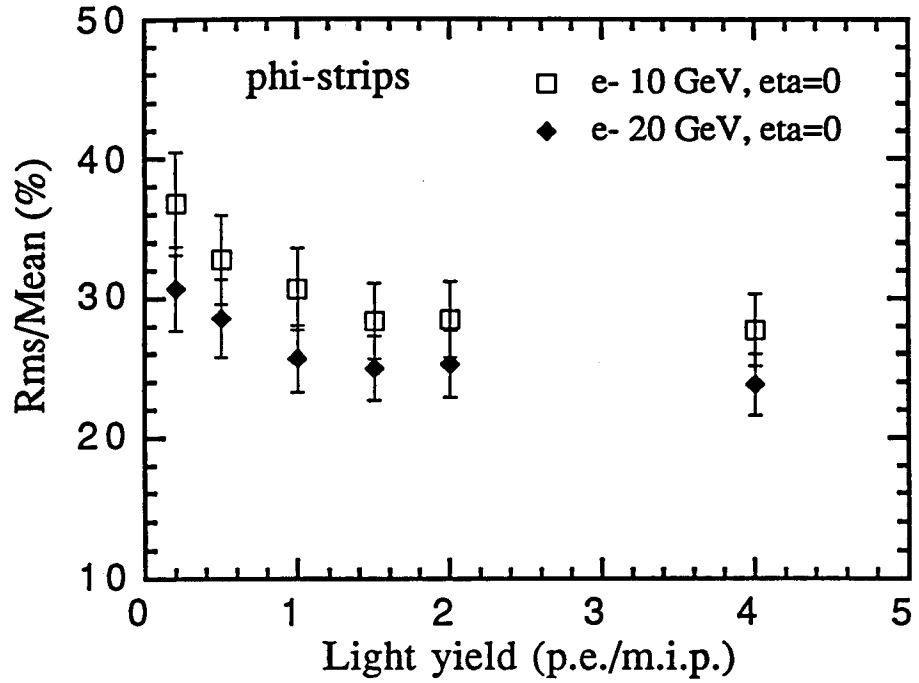


Fig. 10. Shower Max Detector elements for a single 4x4 tower SM slot. Notches are shown on cover platers and on fiber-routing plates only when they will actually be used for fiber routing.



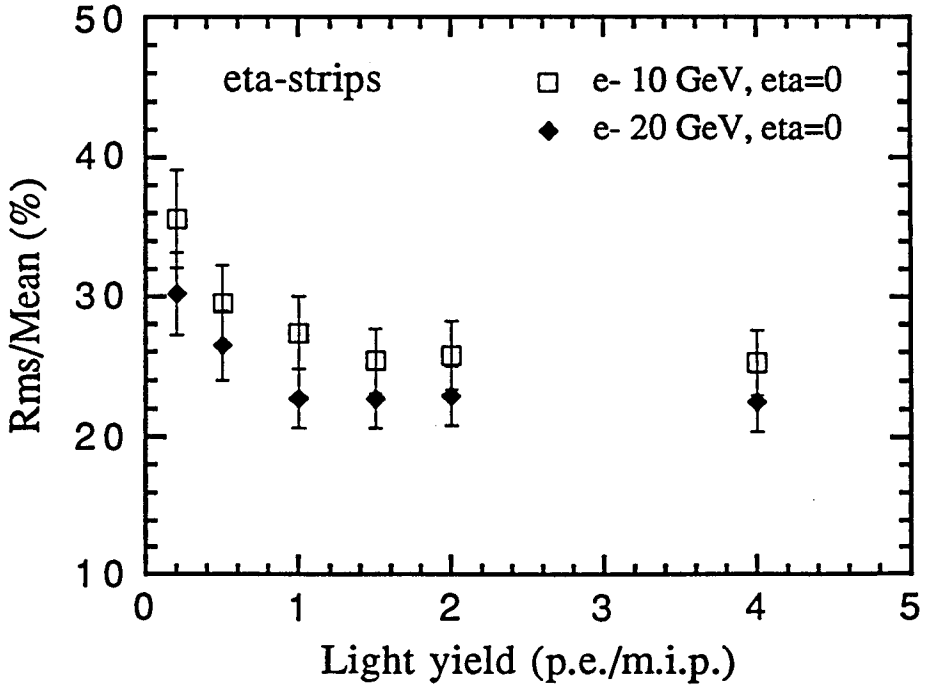


Fig. 11. The SMD energy resolution as a function of the light yield is shown for ϕ-strips (top) and η-strips (bottom).

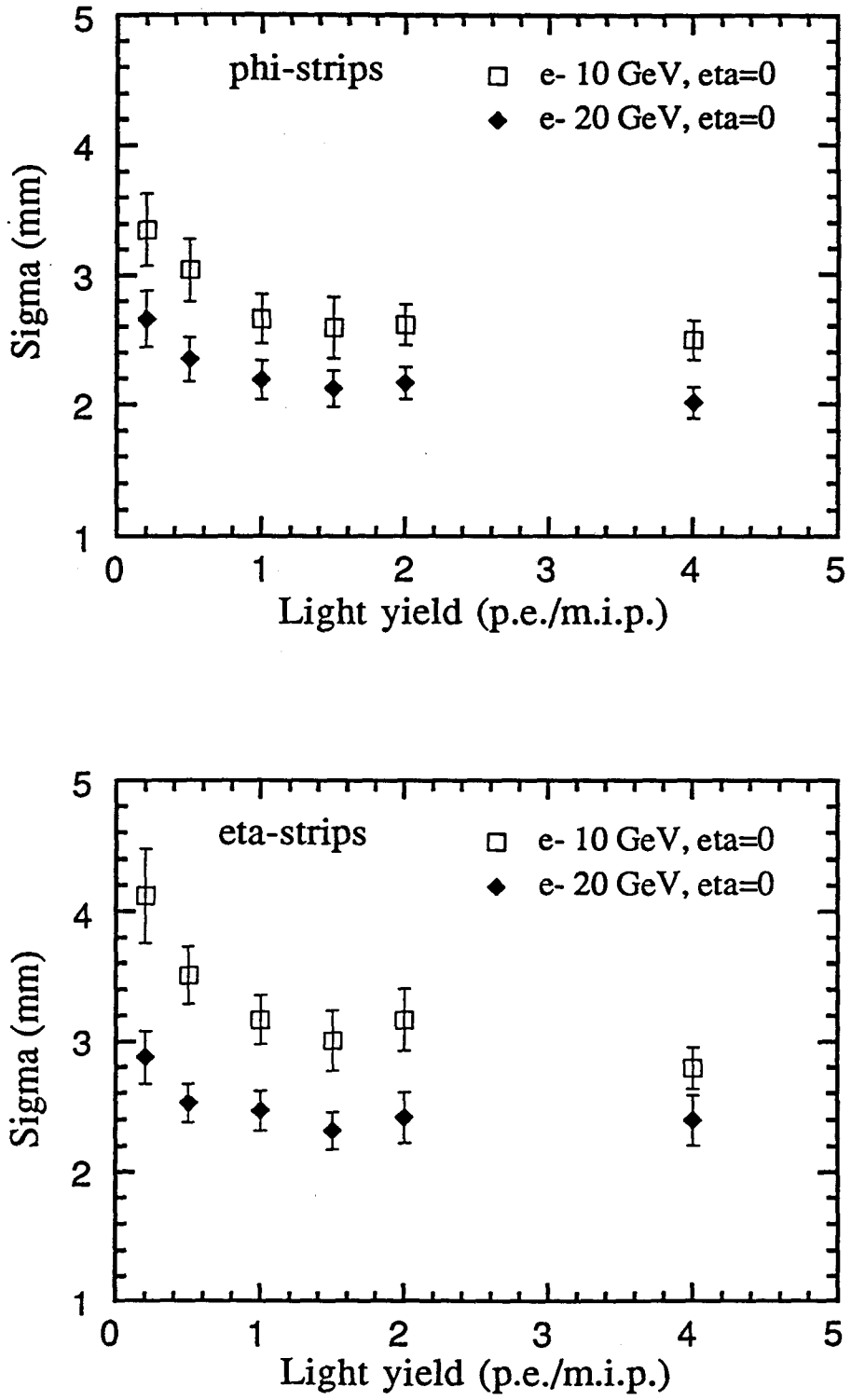


Fig. 12. The SMD position resolution as a function of the light yield is shown for ϕ-strips (top) and η-strips (bottom)

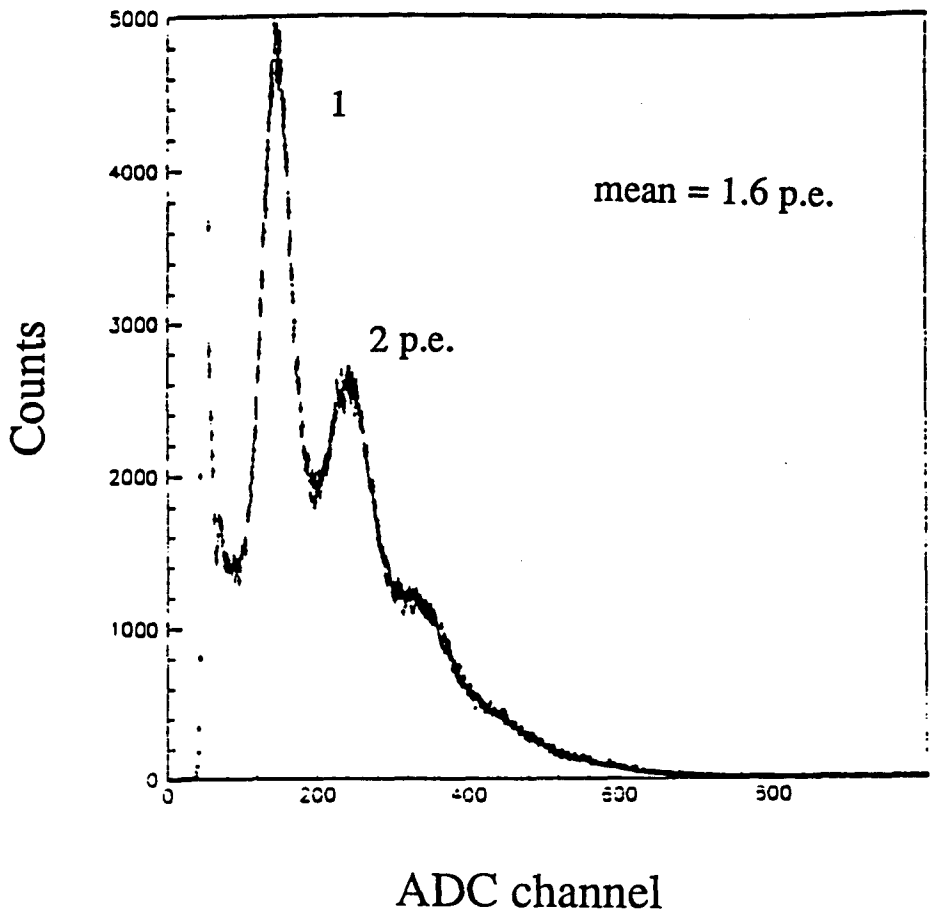


Fig. 13. Pulse height distribution produced by a PMT (RCA 8850) connected to a strip/fiber assembly. The 1, 2, 3 p.e. peaks are visible; the average number of photoelectrons is 1.6 in this particular measurement.

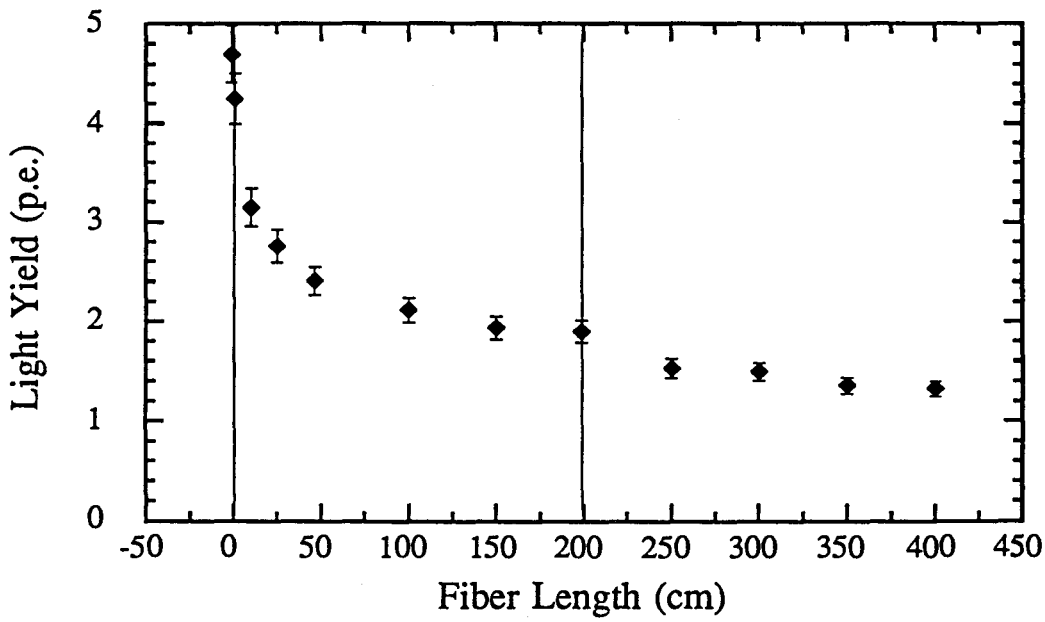


Fig. 14. Light yield from a 20 cm long SM strip as a function of the length of the clear fiber spliced to the WLS fiber. The first splice is at 0 (just outside the strip). The 4 m long clear fiber has a second splice at 2 m.