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Hadron calorimetry test bench

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Abstract. A reconfigurable sampling hadron calorimetry test bench was built. Different scintillator-absorber stack configurations can be easily constructed within the test bench for extensive detector performance studies. Three configurations, with absorber layers of uniform thicknesses of 48 mm, 24 mm, and 16 mm, and with scintillator layers of uniform thicknesses of 4 mm, were studied with electron and hadron beams.

1. Test benches as research and development tools

Sampling calorimetry test benches are among tools that allow diversified, yet inexpensive, research and development projects. Using a test bench, one can carry extensive studies that lead to better optimization of a final detector design, meanwhile reducing the cost of the detector and the cost of R&D. Configurations of a scintillator-absorber stack can be tuned to optimal constant or varying sampling fractions, in order to achieve the best detector performance for the energies of interest. Compensation, metrological, and mechanical engineering options can be optimized with the test bench, as well. Different absorber materials, readout devices and readout electronics can be tried out. Reconfigurable and expandable test benches can offer wealth of studies before one actually progresses to building a prototype detector.

2. Reconfigurable test bench

We designed and fabricated a reconfigurable test bench for hadron calorimetry studies. The components and corresponding quantities of the test bench set are listed in table 1.

The box-case (figure 1), in which the scintillator-absorber stack is placed, is assembled from steel components. Its support is made of a 30 mm thick steel sheet welded to one I-beam and twelve C-beams. Two frames made of sheets with milled windows are each attached to the front and rear ends of the support. Two side walls are attached to the C-beams of the support and to the front and rear frames. Each side wall has milled slots that run with a step of 120 mm along the length of the wall. The scintillator-absorber stack is assembled by placing absorber plates and scintillator tiles on their edges, orthogonally to the support and to the side walls of the box-case. The slots in the opposing walls of the box-case allow fixing the stack for a certain chosen total thickness, using a bracket inside the box-case. If needed, extra steel plates are placed at the end of the scintillator-absorber stack to eliminate a gap between the stack and the bracket.

Table 1. Test bench set.

Component	Quantity
steel box-case	1
scintillator tile (350 x 350 x 4 mm^3)	210
scintillator tile (350 x 350 x 5 mm^3)	14
non-scintillator tile (350 x 350 x 2 mm^3)	232
antimonial lead alloy plates (350 x 350 x 2 mm^3)	380
steel plates (350 x 350 mm^2, various thicknesses)	5
36-fiber bundle (clear waveguides, 2 m)	6
12-fiber bundle (clear waveguides, 2.25 m)	2
4-fiber bundle (clear waveguides, 2 m)	2
2-fiber bundle (clear waveguides, 1 m)	2

The thin antimonial lead alloy plates (antimony content is 10%) allow making absorber layers with different thicknesses, which are multiples of 2 mm. The scintillator-absorber configurations can be chosen with uniform or variable thicknesses of the absorber layers through the depth of the test bench.

The scintillator tiles (figure 2) are made of 98.3% polystyrene, 1.7% p-Terphenyl and 0.01% POPOP. The tiles are enveloped with aluminum foil which, in turn, is enveloped with thin plastic film. Wall plastic paper is put on both surfaces of each tile to protect the foil and thin film envelopes from scratches.

Figure 1. Steel box-case.

Figure 2. Scintillator tiles.

The non-scintillator polystyrene tiles were made to research mechanical design options for real hadron calorimeters. Such non-scintillator tiles can be placed between the scintillator tiles and the absorbers to see how the energy resolution and compensation might be affected by such placement.

Kuraray Y-11 wavelength shifting fiber with a diameter of 1.2 mm is glued, with optical cement, in grooves made in the scintillator tile. Two fiber ends exit the tile through steel tubes glued at both ends of the groove. Equal quantities of the "left" (figure 3) and the "right" (figure

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4) scintillator tiles were made (dimensions in the figures are in milimeters). The fiber layout maps of the "left" and the "right" tiles are mirror images of each other; the "left" and the "right" tiles alternate in the scintillator-absorber stack.

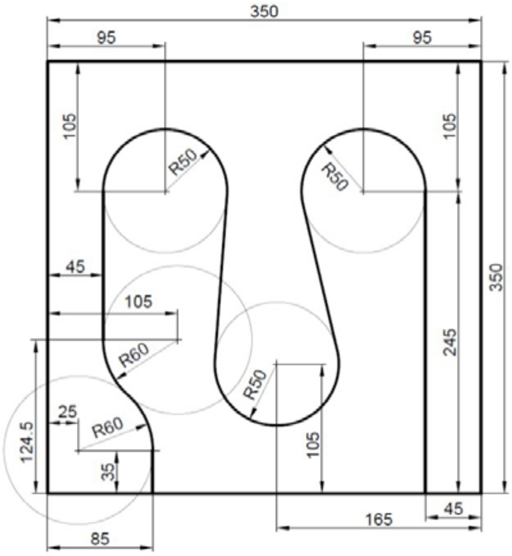

Figure 3. "Left" scintillator tile.

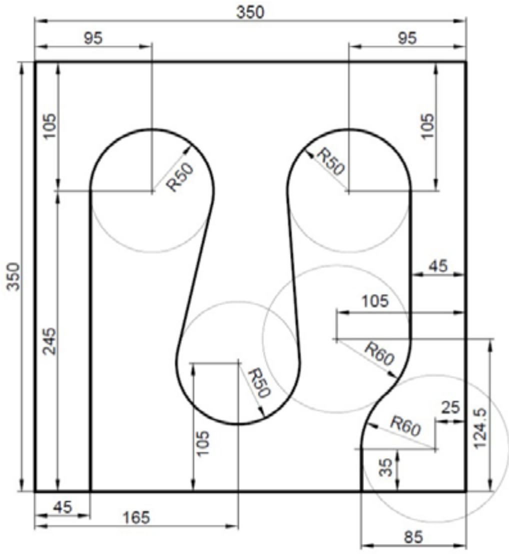

Figure 4. "Right" scintillator tile.

Upon exiting the tile, the steel tube, with the inserted wavelength shifting fiber, is coupled with a clear waveguide fiber that transmits the light to a photomultiplier tube (PMT). Several clear waveguide fibers are bundled together, using a mechanical collet (figure 5), so the cross-sectional surfaces of the clear waveguide fibers can be directly coupled with the PMT window (figure 6). This way, every PMT can serve several scintillator tiles. Depending on chosen thicknesses of the absorber layers, one or several photomultipliers detect the light from the scintillator-absorber stack.

Figure 5. Fiber bundle collet.

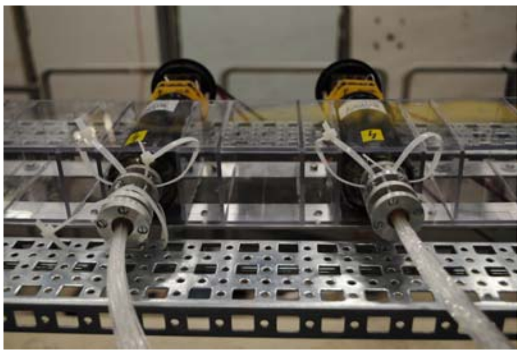

Figure 6. Bundles coupled to PMTs.

The 5 mm thick scintillator tiles were made to study lateral shower leaks. For such studies, these tiles can be attached to the side walls of the box-case.

3. Test beam studies

Performance of the test bench was preliminarily studied at T9 beam line of CERN Proton Synchrotron with beam momenta ranging from 1 GeV/c to 10 GeV/c. Energy signals from hadron (negative pion) and electron beams were measured with three test bench configurations. In the first configuration, 15 scintillator-absorber layers were used. The thickness of every absorber layer was 48 mm. A total of 16 scintillator tiles (one tile was placed at the end of the stack) were read out by 32 fibers of 36-fiber bundle, using one PMT. In the second configuration, the number of scintillator-absorber layers increased to 31. The thickness of each absorber layer was reduced to 24 mm. 32 scintillator tiles (one at the end of the stack) were read out by 64 fibers of two 36-fiber bundles, using two PMTs. In the third configuration, the data were taken with 47 scintillator-absorber layers. The thickness of every absorber layer was 16 mm. 48 scintillator tiles (again, one tile was placed at the end of the stack) were read out by 96 fibers of three 36-fiber bundles with three PMTs. The gains of the PMTs (Philips XP2264/H04) were kept the same for all measurements except for the test of the third configuration with the hardon beam, when the gains were reduced by about a factor of 4. The electromagnetic and hadronic energy resolution functions for all three configurations of the test bench are plotted in figure 7.

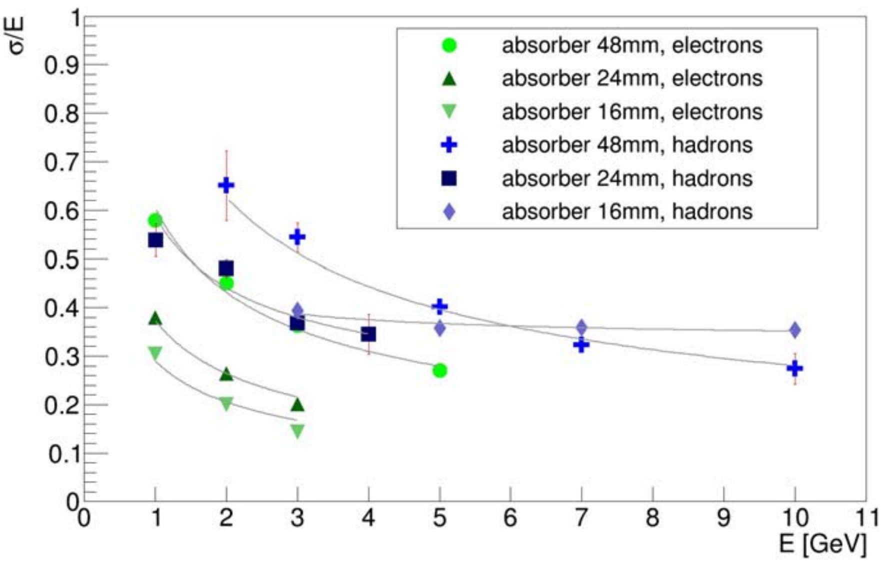

Figure 7. Energy resolutions of the signals from electron and hadron beams.

The energy resolutions as functions of the beam energies were fitted with either $A/\sqrt{E} \bigoplus B$ or $A/\sqrt{E}$. In the configuration with the 48 mm thick absorbers, the electromagnetic energy resolution was found to be $0.601/\sqrt{E} \bigoplus 0.077$, while the hardonic energy resolution was $0.886/\sqrt{E}$. With the 24 mm thick absrobers, the electromagnetic energy resolution was $0.374/\sqrt{E}$ and the hadronic energy resolution was $0.548/\sqrt{E} \bigoplus 0.211$. With the 16 mm thick absorbers in the stack, the electromagnetic and the hadronic energy resolutions were $0.290/\sqrt{E}$ and $0.337/\sqrt{E} \bigoplus 0.335$, correspondingly.

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