U.S. Department of Energy Advanced Detector Research Program

Grant Number: DE-FG02-02ER41223

"Development of Extruded Scintillator and Single-Bit Tracking Calorimetry"

Final report

The R&D activities funded in part by this grant have been successfully concluded. Some adjustments had to be made to the course anticipated in the original proposal. These were necessitated to a large extent by external factors, such as changes in demands for different geometries, and rapid progress in the integration of the silicon-based photodetectors. However, internal factors like improvements in our own understanding the behavior of the extrusion line [1] and that of the extruded scintillator strips also played a role. The table below summarizes some important milestones. These are in accord with the projections in reports submitted in prior years [2,3]. In the present document we focus on the work done since the last report.

Task/Milestone	Date
The NICADD extruder delivered for installation at Fermilab	02/24/03
Assembled and debugged for the first test run	05/06/03
First extruded samples produced	06/03
Extensive simulation of dies (in collaboration with NIU ME dept)	05/03 - 11/03
Testing of samples extruded with 1-10 holes	10/03 – 02/04
Production of first new 2cm x 1cm rectangular die with 1mm hole	02/04
First results on light output and uniformity of response of elements produced by the FNAL-NICADD extruder presented at Calor 2004	0304
Production of 10 cm x 0.5 cm x 100 cm strips with 10 coextruded holes.	05/04
Production of 20 cm x 0.5 cm x 100 cm strips with 2 coextruded holes (for the tail-catcher/muon-tracker (TCMT) section of the CALICE test beam module) [4]	06/04 - 03/05
Extensive characterization and comparison with alternative technologies: light yield, uniformity of geometry and response, radiation hardness etc.	06/04 - 10/05
Results from much of the above presented at the IEEE/NSS conference	10/04
Results from extensive testing of CALICE strips presented at LCWS	10/05
Construction of the TCMT using NICADD extruded scintillator strips	06/05 - 03/06
Beam tests of the CALICE test beam module including the 16-layer TCMT - first at CERN and later at Fermilab.	06/06 – present
First beam test results presented at conferences	06-07

Table 1. Important milestones achieved in the course of the project.

We are pleased to report also that the final task on the list in our proposal, namely "Production and integration of cells for the test-beam module" was a resounding success, albeit with the modified choice of strips operating in analog mode. This solution for the TCMT module was adopted by the CALICE collaboration [5] to meet budgetary constraints since the Si photodetectors remain rather expensive. Planes of trips are packaged into "cassette"s that slide between absorber plates, as shown in Fig. 2. of the last report [3] and in Ref. [4]. Figure 1 below shows the response from individual strips when a plane is scanned across with a 5 GeV electron beam at DESY.

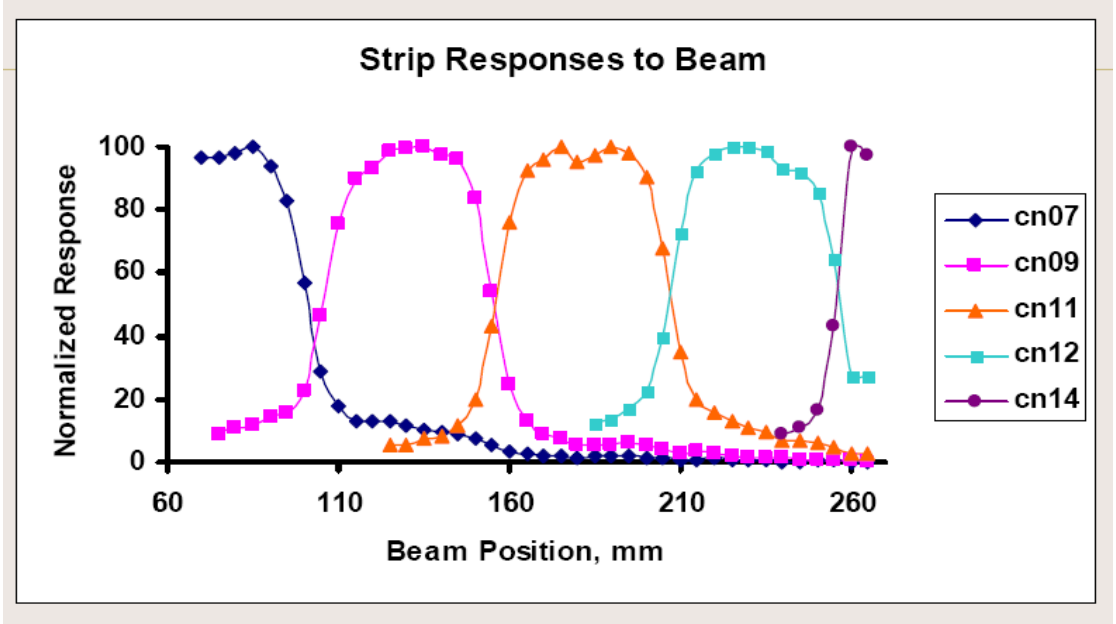

Figure 1: Individual strip response from a transverse scan of a TCMT plane with 5 GeV electrons at DESY.

Figure 2 shows the TCMT ready to be shipped to CERN. Including the photodetectors, each cassette is 102 cm x 109 cm x 1.5 cm. The first (last) 8 stainless steel absorber planes are 2 cm (10 cm) thick. The strips in alternate layers are oriented perpendicular to each other. Including the support structure, the TCMT measures approximately 1.3 m x 1.3 m x 1.6 m and weighs 20 tons.

Beam tests at CERN demonstrated a marked improvement in single-particle energy resolution when the information from the upstream Analog Hadron Calorimeter (AHCAL) is supplemented by that from the TCMT. Both the SiD and ILD full-detector concepts under development for the future ILC envisage a relatively thin calorimeter (~4.5 λ electromagnet+hadronic combined) that can fit inside a ~4 T solenoid. The entire length of a shower often cannot be contained within that depth. A substantial amount of energy punches through. Placing the TCMT behind the solenoid helps improve the energy resolution, as shown in Fig. 3.

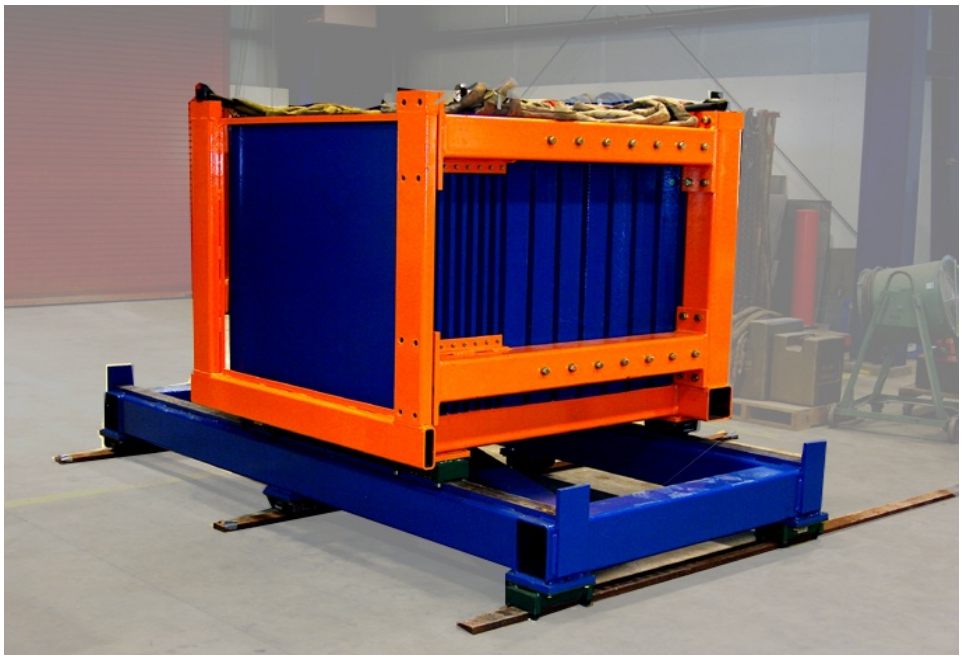

Figure 2. The tail-catcher/muon-tracker (TCMT) ready for shipment to CERN.

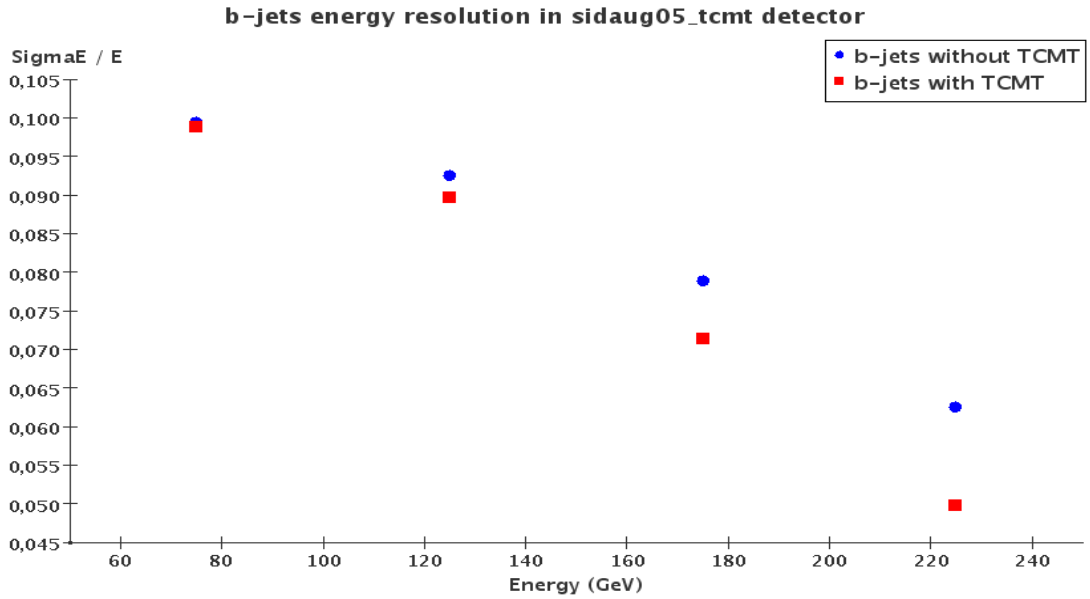

Figure 3: The improvement in b-jet energy resolution of the SiD detector as a result of supplementing the calorimetric information with the TCMT (simulation).

The results have been reported at a number of conferences and workshops, including the Calor conference (2006) [6] and the International Linear Collider Workshop (2007) [7], and are currently being prepared for publication.

In conclusion, we have demonstrated that extruded scintillator strips with co-extruded holes for fibers are a viable solution for the outermost layers of an ILC calorimeter as well as for MINERva [8]. For the inner layers of an ILC calorimeter, where fine segmentation in both lateral dimensions are desirable (that is, small tiles instead of strips), fibers can be eliminated in favor of direct coupling between the scintillator and the photodetector, and alternative production mechanisms, such as injection molding, or machining cast scintillators, are better suited. It was also found that analog readout is potentially a better option than single-bit "digital". These latter observations follow from our continued investigations funded in part by a separate and subsequent ADR grant.

At various points of time over the duration of the project, up to four graduate students and two undergraduates worked alongside the senior personnel. In addition to the scientific outcome, the project thus provided a significant opportunity for education.

To summarize, the proposed R&D was conducted according to plans. The DoE's funding of this project under the Advanced Detector Research program (Grant # DE-FG02-02ER41223) was used, in accordance to the budget sheet, to pay a part of Dr. Rykalin's salary. Rykalin served as NIU's liaison to the extruder facility and to consumers (the MINERvA and CALICE collaborations). He also took a major responsibility in overseeing the day-to-day operation of the FNAL-NICADD extrusion line.

References

1. The FNAL-NICADD Extruded Scintillator Project (FNESP), http://nicadd.niu.edu/research/extruder/ and references therein.
2. "Development of Extruded Scintillator and Single-Bit Tracking Calorimetry": Progress report for FY2003, http://nicadd.niu.edu/~dhiman/adr03/adr_report_FY2003.pdf
3. "Development of Extruded Scintillator and Single-Bit Tracking Calorimetry": Progress report for FY2004, http://nicadd.niu.edu/~dhiman/adr03/adr_report_FY2004.pdf
4. http://www.niu.edu/nicadd/research/lcd/tcmt/index.shtml
5. The CALICE (CAlorimetry for the LInear Collider with Electrons) Collaboration, https://twiki.cern.ch/twiki/bin/view/CALICE/WebHome
6. http://www.hep.anl.gov/CALOR06/.
7. http://lcws07.desy.de/ .
8. The MINERvA experiment, http://minerva.fnal.gov/