Journal of Physics: Conference Series

Preliminary Results from a Test Beam of ADRIANO Prototype

To cite this article: C Gatto *et al* 2012 *J. Phys.: Conf. Ser.* **404** 012030

XVth International Conference on Calorimetry in High Energy Physics (CALOR2012) IOP Publishing
Journal of Physics: Conference Series **404** (2012) 012030 doi:10.1088/1742-6596/404/1/012030

Preliminary Results from a Test Beam of ADRIANO Prototype

C Gatto[1], V. Di Benedetto[2] and A. Mazzacane[3]
On behalf of T1015 Collaboration
[1] INFN, Sezione di Napoli, via Cinthia, 80126 Napoli, Italy
[2] INFN, Sezione di Napoli and Università del Salento - Lecce, Italy
[3] Fermilab, Batavia (IL), USA

E-mail: `corrado.gatto@infn.it`

Abstract. The physics program at future colliders demands an energy resolution of the calorimetric component of detectors at the limits of traditional techniques. The ADRIANO technology (*A Dual-readout Integrally Active Non-segmented Option*) is under development with an expected excellent performance. Results from detailed Monte Carlo studies on performance with respect to energy resolution, linear response and transverse containment and a preliminary optimization of the layout are presented. A baseline configuration is chosen with an estimated energy resolution of $\sigma(E)/E \approx 30\%/\sqrt{E}$, to support an extensive $R\&D$ program recently started by *T1015* Collaboration at Fermilab. Preliminary results from a test beam at the *Fermilab Test Beam Facility* (FTBF) of a $\sim 1\lambda_I$ prototype are presented, along with simulation studies. Future prospects with ultra-heavy glass are, also, summarized.

1. Introduction

The physics program envisaged for the experiments at future lepton and hadron colliders will be dominated by studies of processes involving multi-jets event. In such an environment, calorimeters will play a fundamental role as particle detector. A broad based $R\&D$ and Monte Carlo simulation activity is already in progress within the lepton colliders communities[1].

A consensus has been established on the fact that the minimum hadronic energy resolution of the calorimetric systems needed to successfully distinguish the W from the Z signal is $\sigma(E)/E \approx 30\%/\sqrt{E}$. Such a resolution is unprecedented and it is being reached only by massive compensating calorimeters with very small volume ratio between passive and active materials[2]. However, the large size needed to contain the showers, because of their relatively low density, make them impractical to build in experiments with colliding beams. As a consequence, it would be challenging to achieve at the same time effective compensation and shower containment. Furthermore, the resolution of traditional calorimeters is limited, among other sources, by the fluctuation in the electromagnetic (EM) content of the hadronic shower and by the unequal response of such devices to the EM and hadronic components of the shower itself[3]. In recent years, an alternative technique has been developed in order to cope with such effects: the dual-readout calorimetry[7], based on an event-by-event measurement of the EM fraction of the shower. Such a technique is based on the simultaneous measurement of signals generated by different shower production mechanisms, thus providing complementary information on the composition of the hadronic shower. When applied to a realistic detector layout expected at an experiment at a high energy collider, such a technique appears capable of meeting the necessary requirements[5].

The dual read-out calorimetry falls under two broad categories: sampling and integrally active. Sampling dual-readout techniques are currently investigated by the DREAM[7] and the 4th Concept Collaborations[5]. Test beams and extensive simulations have proved that these techniques provide excellent energy resolution. However they introduce two important sources of fluctuations: Poisson fluctuations in the Čerenkov signal, induced by the low photo-electron statistics and sampling fluctuations. These fluctuations do not only impair the energy resolution for hadronic showers, but have also detrimental consequences on the detection quality of photons and electrons. Consequently, the detection of high energy jets where a large contribution by EM particles occurs is similarly affected. An obvious solution to the latter problem would be to design a detector with two distinguished regions: a front EM section and a rear hadronic section. However, it is well known that such a configuration, most often consisting of media with very different properties, is sub-optimal in terms of energy measurement of hadronic particles due to the extra fluctuations introduced by the development of the shower into two different sections [3].

In this article we propose a novel Dual-Readout, Integrally Active and Non-homogeneous Option (ADRIANO), based on signals produced in high transmittance optical glasses and scintillating fibers that has the potential to overcome the above limitations.

2. Description of ADRIANO technique

The new detection technique named ADRIANO (*A Dual-readout Integrally Active Non-segmented Option*) is a part of an extensive *R&D* program recently started by *T1015*[4] Collaboration. ADRIANO prototypes recently built all have a modular structure, with the base unit consisting of an individual cell of parallelepiped shape with $40 \times 40\ mm^2$ cross-section and either 15 cm or 25 cm length. The cell consists of a sandwich of scintillating fibers and high density, optical grade heavy glass. The glass behaves as an absorber and as an active medium at the same time, generating almost exclusively Čerenkov light. The scintillation and Čerenkov sections of ADRIANO are optically separated. Therefore, the two generated lights are well separated, with minimal chance of cross-talk. For the results presented in this report, we have considered various techniques to optically separate the two regions: white and silver coating of the glass, white coating, silver coating and aluminum sputtering of the scintillating fibers and finally, a thin layer of Teflon between the glass plates and the array of scintillating fibers.

The scintillating fibers are either accommodated in grooves in the glass itself or in white plastic trays sandwiched among plates of glass. They run parallel to the longitudinal axis of the cell and are responsible for the generation of the scintillation component of the dual readout calorimeter. The pitch between nearby fiber is sufficiently small compared to the nuclear hadronic interaction length of the detector so that the shower sampling fluctuations are small.

The Čerenkov light generated in the glass plates is collected by WLS fibers running inside grooves parallel to the scintillating fibers and optically coupled to the glass by especially formulated optical compounds. The two light components are read out at the back of each cell with two distinct photodetectors. In some sense, ADRIANO is a spaghetti calorimeter with the passive absorber replaced by an active, transparent absorber made of heavy glass. Another advantage of ADRIANO relies on the fact that the heavy glass absorber can be used to detect electromagnetic showers in exactly the same ways as it has been done in the past with lead glass based electromagnetic calorimeters. Therefore, ADRIANO does not require a front electromagnetic section.

Several heavy glasses (mostly lead and bismuth based) have been tested, with the intent of comparing the Čerenkov light yield and propagation. Their refractive index ranges from 1.85 through 2.24 while the densities range from $5.5 gr/cm^3$ through $7.5 gr/cm^3$. Several constructions techniques have been considered: diamond machining, precision molding, glass

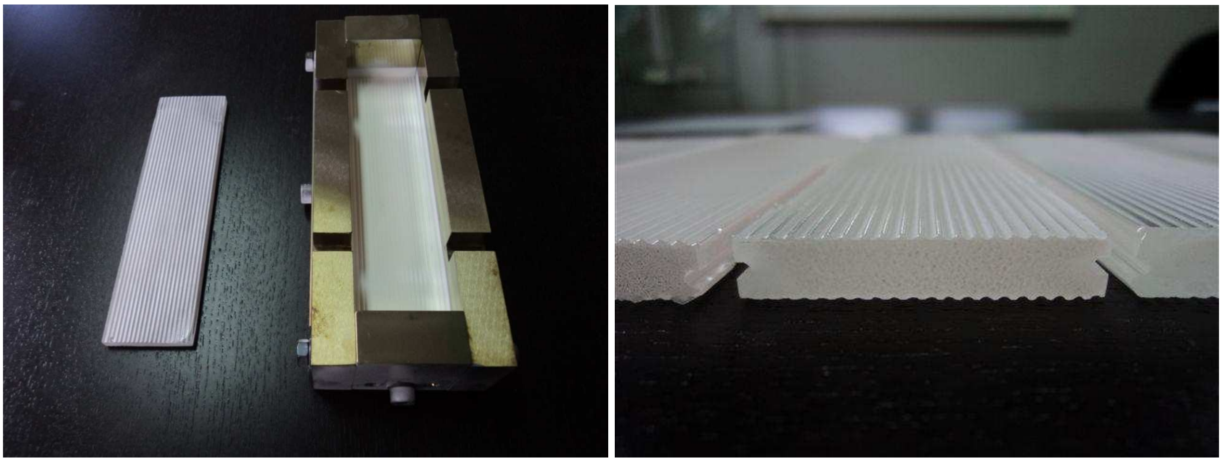

Figure 1. *Molding fabrication technology.*

melting, laser drilling and photo-etching. However, only the former two have been considered for the production of the eleven ADRIANO prototypes presented in this report. A picture of a $8mm$ thick glass slice obtained with the precision molding technique is shown in Fig.1 . A detailed description of the layouts of the eleven prototype and their corresponding construction techniques will follow in an upcoming article.

3. ADRIANO readout system

The scintillating and WLS fibers from each ADRIANO cell were bundled and routed each to a photodetector. In order to compare the performance of the light collection system in variuos situations we used three different photomultipliers (R647 and H3165 from Hamamatsu and P30CW5 from Sensetech) and two different SiPM ($4x4mm^2$ square and $\varnothing 2.7mm$ round from FBK) for WLS fibers and only one type of SiPM ($4x4mm^2$ square from FBK) for the scintillating fibers. When PMT were used, the fibers were routed through a plastice fixture and coupled to the photosensor window with a custom made optical grease. In the case of SiPM, we used either acrylic ligth concentrators (designed and produced by INFN Trieste) in direct contact with the fibers on one side and spaced $0.1m\mu$ from the active SiPM surface or we routed the fibers directly to the SiPM up to $0.1m\mu$ from the active SiPM surface. A picture of a INFN-Trieste light concentrators is shown in top left of Fig.2. The output of the SiPM and PMT used was digitized by the TB4 DAQ system developed at Fermilab. Among the features of the DAQ, the most relevant for our application are:

- 50Ω inputs
- 14 bit ADC;
- $\sim$ 30 MHz bandwidth;
- $\sim$ 212 MSPS digitizer;
- Up to 16 channels per Motherboard;
- Bipolar, so both positive (from SiPM) and negative (from PMT's) signals can be acquired simultaneously;
- Slow-control over USB, readout over 100 Mbit Ethernet.

4. Preliminary Results From Test Beams

From March 2011 through April 2012 four test beam have been completed at FTBF Facility of Fermilab (Batavia, US). A total of eleven ADRIANO cell prototypes (with different dimensions)

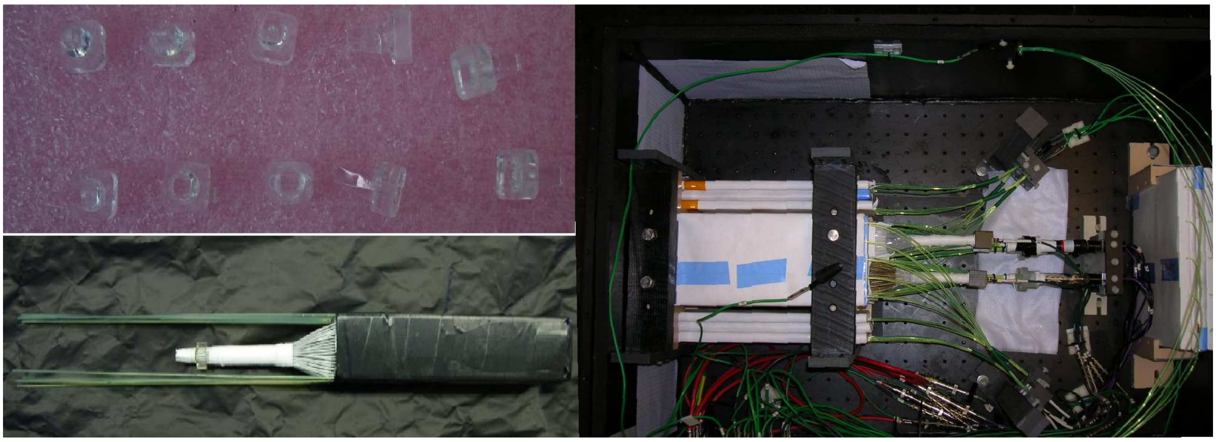

Figure 2. *INFN-Trieste light concentrators, a typical ADRIANO prototype, with scintillating fibers bundled together and WLS unbundled on the left and 2012 test beam setup at FTBF on the right.*

in different configurations and with different construction techniques have been illuminated by the secondary beam available at FTBF. A picture of a typical ADRIANO prototype, with scintillating fibers bundled together and WLS unbundled is shown in the bottom left of Fig.2 In summary we have tested:

- 4 glass type: lead and bismuth based.
- 2 glass coatings: TiO2, Silver paint.
- 3 WLS fibers: Y11 (1.2 mm) & BCF92 (1.0 mm, 1.2 mm).
- 1 Scintillating fiber: SCSF81.
- 4 scifi coating: TiO2, BasO4, Silver paint, Al sputter.
- Several optical glues (mostly custom made).
- 5 photodetectors: 2 SiPMs (ø$2.7mm$ round and $4x4mm^2$ square) & 3 PMTs (P30CW5 , R647, H3165)
- 4 light coupling systems: direct glass + direct WLS + 4 light concentrators

The goal of these experiments were to optimize the construction technique and the materials used in order to maximize the Čerenkov light yield. We also measured some of the parameters that were needed for Monte Carlo simulations with ILCroot framework [8]. Due to the limited size of the cells, we do not expect to be able to to test the dual-readout concept nor to evaluate the energy resolution of ADRIANO.

Typical waveforms for several beam configurations, as obtained by TB4 DAQ, the Čerenkov spectrum various prototypes when exposed to a 5 GeV beam at FTBF and the uniformity of Čerenkov response across the cell are shown in Fig.4 (right side).

Finally, the Čerenkov light yield from the eleven prototypes tested at FTBF is summarized in Table 1.

5. Summary of results

Since the start of ADRIANO *R&D* program, we were able to constantly improve the Čerenkov light yield by refining the construction techniques and the materials employed. The current limit for a $40x40x250mm^3$ is roughly 160 pe/GeV. We found that the Čerenkov light attenuation length inside the glass absorber critically depends on coating type and on the surface finishing of

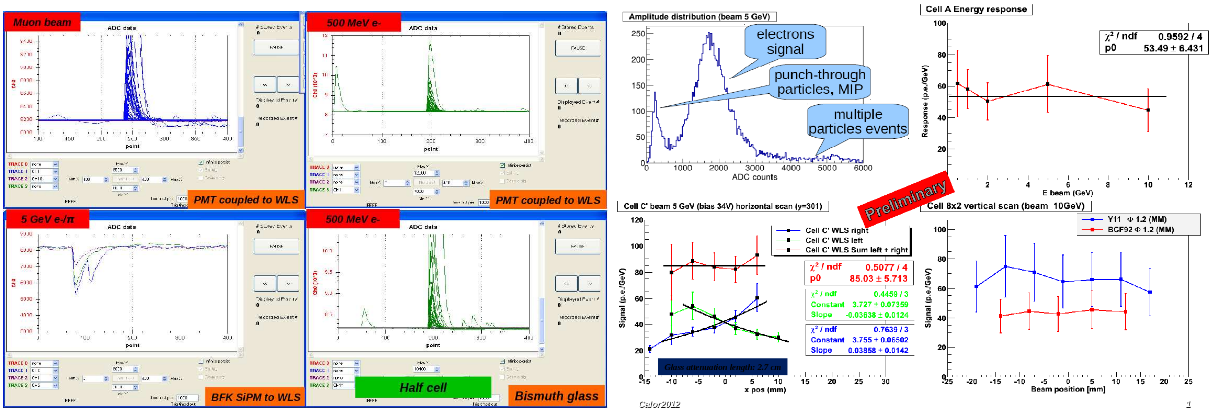

Figure 3. *Typical waveforms,the Čerenkov spectrum from various prototypes and the uniformity of Čerenkov response.*

Prototype #	Layout	Glass	gr/cm^3	L.Y	Notes
1	5 slices, machine grooved, unpolished, white	Schott SF57HHT	5.6	82	SiPM readout
2	5 slices, machine grooved, unpolished, white, v2	Schott SF57HHT	5.6	84	SiPM readout
3	5 slices, precision molded, unpolished, coated	Schott SF57HHT	5.6	55	15 cm long
4	2 slices, ungrooved, unpolished	Ohara BBH1	6.6	65	Bismuth glass
5	5 slices, scifi silver coated, grooved, clear, unpolished	Schott SF57HHT	5.6	64	15 cm long
6	5 slices, scifi silver coated, grooved, clear, unpolished	Schott SF57HHT	5.6	120	improoved version
7	10 slices, white, ungrooved, polished	Ohara PBH56	5.4	> 30	DAQ problems
8	10 slices, white, ungrooved, polished	Schott SF57HHT	5.6	76	
9	5 slices, wifi Al sputter, grooved, clear, polished	Schott SF57HHT	5.6	30	2 wls/groove
10	5 slices, ungrooved, polished	Schott SF57HHT	5.6	158	Small wls groove
11	2 slices, plain	Ohara experimental	7.5	–	DAQ problems

Table 1. Summary of light yields for ADRIANO modules for 2011-2012 test beams.

the glass slice. Coupling of fibers to SiPM's is critical as well; any thin air gap between the light concentrator and the active surface of an SiPM more than halves the light yield. Kuraray Y11 fibers produced almost 50% more light than Bicron BCF92 with the same diameter. Different optical glues, used to couple the glass to WLS fibers produced up to a factor of 2 in variation of light yield. This result should not surprise since we are attempting to collect light from an optical medium with considerably large refractive index ($1.8-2.2$) by transferring the Čerenkov light to plastic fiber with far lower refractive index (typical refractive index of the external cladding of WLS fibers is 1.45). Cold vs hot glass construction methods make no appreciable difference in Čerenkov light yield. Direct reading of Čerenkov light from glass with an acrylic light guide coupled to the back of a cell yields consistently less light than when reading using the WLS fibers coupled longitudinally to the cell. This is a clear indication of the fact that, with thin layers of heavy glass having an absorption length of few centimeters, it is preferable to use light collection mechanisms based on WLS fibers distributed across the glass where the short path traveled by Čerenkov photons more than compensates the lower light collection efficiency. SiPM and PMT produce comparable signals, when their respective gains are taken into account. However, large noise from present generation of SiPM make them hard to use in low energy applications. This situation should quickly improve with the latest, low noise, generations of silicon devices.

6. Future Prospects

The first two year of ADRIANO $R\&D$ have already produced clear directions. Precision molding technique is, at present, the preferred fabrication technique since it has the potential of making quick (less than 30 minutes) glass slices with optical surface finish and with appropriate grooves. Nonetheless, we will keep exploiting other fabrication techniques as they might have other potential advantages when compared to precision molding. Photo-etching techniques, for example, are expected to be equally fast and cheap, although they present quite severe chemical hazards.

A great boost in ADRIANO development is currently obtained with Ohara sponsorship/partnership as they provided bismuth glass strips of commercial optical glass ($6.6gr/cm3$, $nd = 2.0$) and strips of an even denser experimental glass with density of $7.54gr/cm^3$ and refractive index of 2.24.

7. Conclusions

In this report we have presented the novel ADRIANO dual-readout technique along with preliminary results from several test beam at FTBF of eleven ADRIANO prototypes. The Čerenkov light yield we have obtained across the board is more than adequate for an hadronic calorimeter with an energy resolution of 30%/sqrt(E) or better. Our goal is to increase the light yield to a level that ADRIANO can be used as an electromagnetic and hadronic calorimeter at the same time. Hardware $R\&D$ and Monte Carlo simulations are in advanced state. More generally, current results from several test beams proved that Čerenkov light readout from heavy glasses with WLS collection system is feasible and provides equal or better results than traditional methods employing a large area PMT directly coupled to the glass. Correctly matching calorimetric techniques with SiPM and Front End Electronics is also crucial for a good performance of the detector. T1015 Collaboration will address these issues in the future and it will exploit new calorimetric techniques based on heavy glass, including scintillating heavy glasses.

8. Acknowledgments

We would like to thank Fermilab for its on-going support and for providing all the infrastructure for the construction and testing of ADRIANO prototype. We also would like to thanks Ohara for providing us with free samples of their BBH-1 bismuth based glass and of a new super-dense (about $7.5gr/cm^3$) experimental glass which have been used for the construction of ADRIANO prototype #6 and #11.

References

[1] $http://www.linearcollider.org/\ http://clic-study.web.cern.ch/clic-study/$
[2] S. Buontempo et al., “Construction and test of calorimeter modules for the CHORUS experiment”, Nucl. Instr. and Meth. A 349 (1994), p. 250.
[3] R. Wigmans, Calorimetry energy measurement in particle physics, in: International Series of Monographs on Physics, vol. 107, Oxford University Press, Oxford, 2000.
[4] $wwwppd.fnal.gov/FTBF/MOU_PDF/T1015\_mou.pdf$
[5] 4th Concept Collaboration - Letter of Intent from the Fourth Detector ("‘4th"') Collaboration at the International Linear Collider, 2009 also at: http://www.4thconcept.org/4LoI.pdf
[6] N. Akchurin, et. al, “New Crystals for Dual-Readout Calorimetry”, Nucl. Instr. Meth. A604(2007)512-526
[7] All DREAM papers are accessible at http://www.phys.ttu.edu/dream, and also http://highenergy.phys.-ttu.edu.particle physics, in: International Series of Monographs on Physics, vol. 107, Oxford University Press, Oxford, 2000.
[8] $http://www.dmf.unisalento.it//\ danieleb/IlcRoot/$