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Scintillating Glasses for Total Absorption Dual Readout Calorimetry

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Abstract. Scintillating glasses are a potentially cheaper alternative to crystal - based calorimetry with common problems related to light collection, detection and processing. As such, their use and development are part of more extensive R&D aimed at investigating the potential of total absorption, combined with the readout (DR) technique, for hadron calorimetry. A recent series of measurements, using cosmic and particle beams from the Fermilab test beam facility and scintillating glass with the characteristics required for application of the DR technique, serve to illustrate the problems addressed and the progress achieved by this R&D. Alternative solutions for light collection (conventional and silicon photomultipliers) and signal processing are compared, the separate contributions of scintillation and Cherenkov processes to the signal are evaluated and results are compared to simulation.

1. Introduction

Energy resolution in Hadron Calorimetry is limited by:

- (a) event-to-event fluctuations in the relative fractions of e.m. (f_{em}) and hadronic ($1-f_{em}$) of the energy deposited by the hadronic shower ($\langle E_{had} \rangle = e \langle f_{em} \rangle + h(1 - \langle f_{em} \rangle)$), coupled with differences in the calorimeter responses (e and h , respectively) to these components;
- (b) fluctuations in the component of *invisible energy* E_i (which corresponds to nuclear binding energy and invisible reaction products). Corrections for $\langle E_i \rangle$ are generally incorporated in h with its consequent fluctuation;
- (c) fluctuations in leakage corrections which, because the interaction length $l_{int} \gg X_0$, are difficult to eliminate completely.

Setting $e/h = 1$ (*compensation*) by alternating the active material with appropriate passive material will help, while improving containment, but at the expense of introducing *sampling fluctuations*. Measurement of deposited energy by independent means, e.g. "Dual readout" (DR) of Cerenkov (C) and scintillation (S) signals, is an alternative means of obtaining compensation but it has, as yet, only been tested in sampling calorimeters. Assuming, however, that DR can be applied to total absorption calorimeters one could obtain compensation while avoiding the sampling fluctuations. A high degree of segmentation would facilitate the correction of leakage fluctuations [1] and might also allow for the application of PFA methods (Magill, this conference [2])

This is all, in principle, possible using scintillating crystals and those suitable for Total Absorption Hadron Calorimetry (TAHCAL) have been reviewed by Ren-Yuan Zhu at this conference [3].

Scintillating glasses might afford a cheaper alternative but heavy glasses with the required characteristics have yet to be developed. A lighter scintillating glass [4] which appears to have the required properties (except for l_{int}) is presently available at FNAL as a legacy of E705 (characteristics are summarized in fig.1) . Although the glass is too light for implementation of TAHCAL in compact collider detectors it can be used to investigate problems related to light collection and separation of the C and S signals in homogenous calorimeters and, assuming the glass characteristics are confirmed to be suitable , one might use the available glass to configure a module for a proof of principle test of TAHCAL. The work reported in this paper is aimed at verifying the properties of the glass (shown in

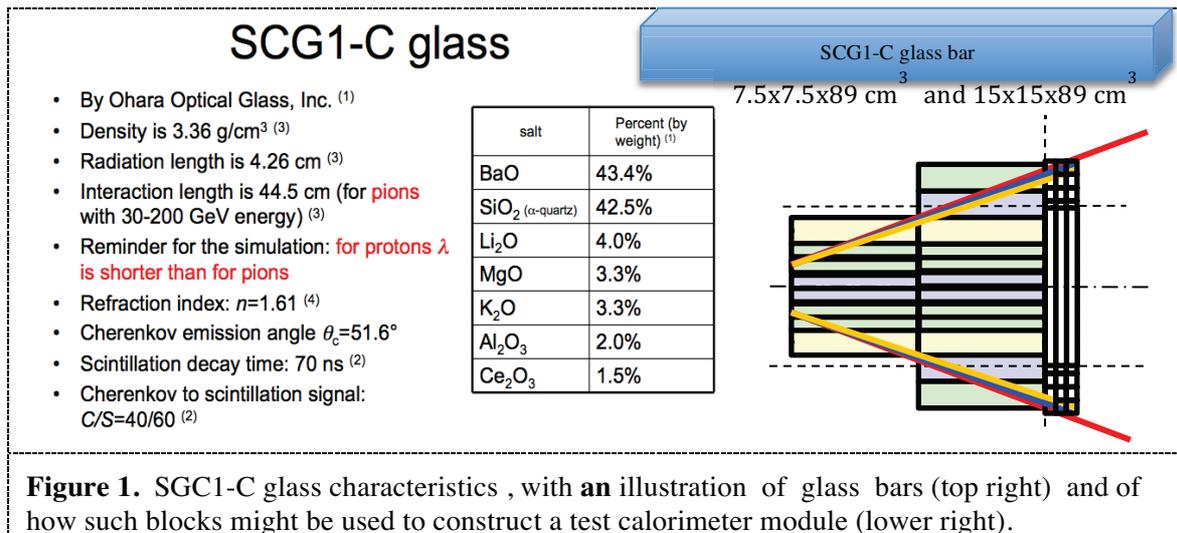


fig. 1), determining unknown properties such as the relative intensities of the G and S signals for both minimally ionizing particles (mips) and hadron showers, determining under which conditions they may be separated and identifying the best combination of photodetector and readout electronics for the purpose.

2. Tests using Cosmics

Preliminary tests were performed at FNAL using cosmics. A schematic representation of the setup is shown in fig. 2. The average of a typical digitized signal (amplitude vs time) triggered by cosmics is shown in the insert on the right. The distinction between the fast Cherenkov (C) contribution and the slower (decay time ~ 70 ns) Scintillation (S) is evident and evaluation of their respective contributions is clearly possible. Absolute light yields were measured by calibrating the PMT gains and their line shapes were measured using a picosecond laser and by observing signals due to single photoelectrons.

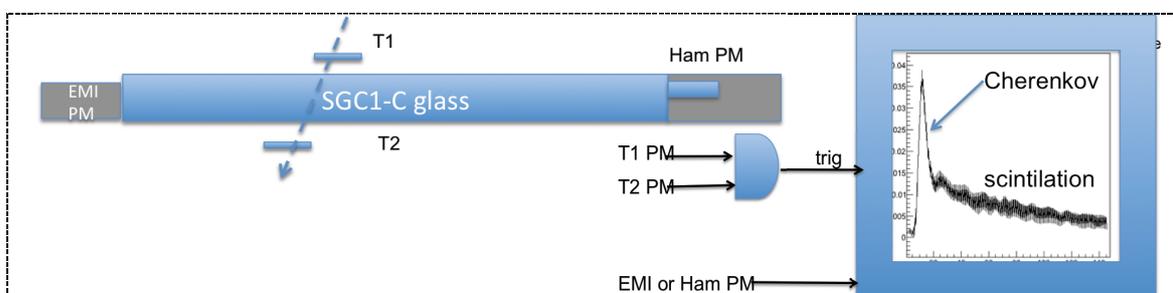


Figure 2. Schematic illustration of lay-out for acquisition of cosmic data. The path of cosmics traversing the SGC1-C glass is defined by counters T1 and T2. Their coincidence triggers a GHz scope which digitizes signals from EMI and Hamamatsu PMs viewing opposite ends of the glass.

Both Cherenkov and scintillation signals were simulated using GEANT 4 and their combinations were fitted to the data to extract the ratio C/S. Given the number of Cherenkov photons generated by the simulation, the number of scintillation photons per MeV was found to be about 600.

3. Tests using using particle beams

Particle beams from the Fermilab Meson Test Beam Facility (MTBF) were used to test the response of these glasses to hadrons and to investigate readout with silicon-based photodetectors (because of their much smaller sensitive areas, cosmic rates in these detectors were much too small to be useful) The experimental setup at MTBF is shown in fig 3. Several silicon-based photodetectors [6] viewed

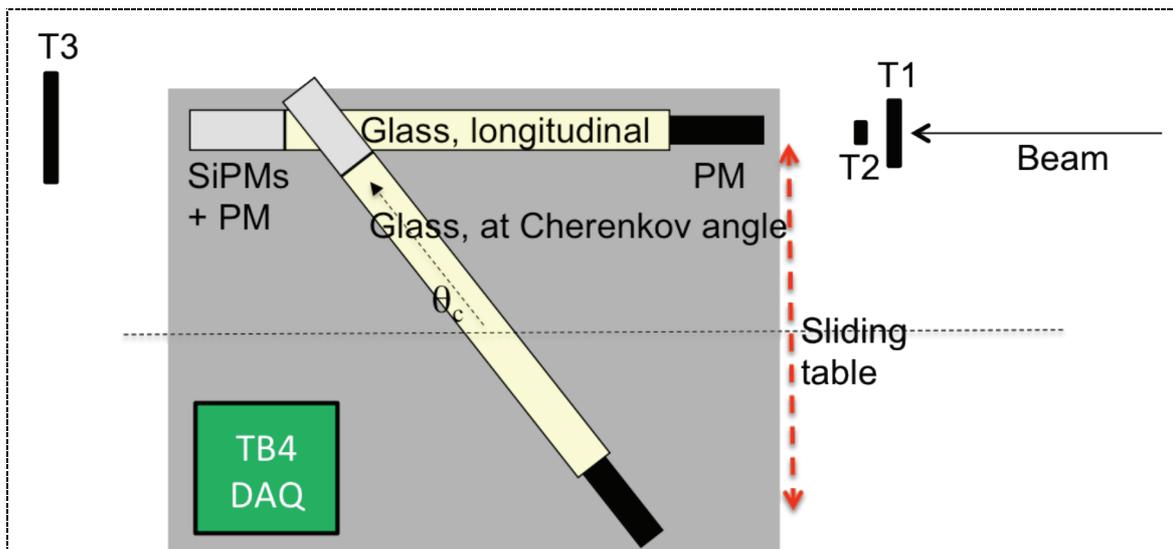


Figure 3 is a schematic illustration of the experimental layout at MTBF. Two glass orientations are illustrated: parallel to the beam direction (“longitudinal”) for maximal harmonic shower production and at the Cherenkov angle θ_c w.r.t. the beam direction.

the signals from the same end of the glass as the Hamamatsu PM (see fig. 3). Their signals were read out and digitized by TB4 [7] DAQ system developed in-house at FNAL. PM signals were read out and digitized commercial system, [8] with higher (~500 MHz) bandwidth and much higher (up to 5 GHz) sampling rate.

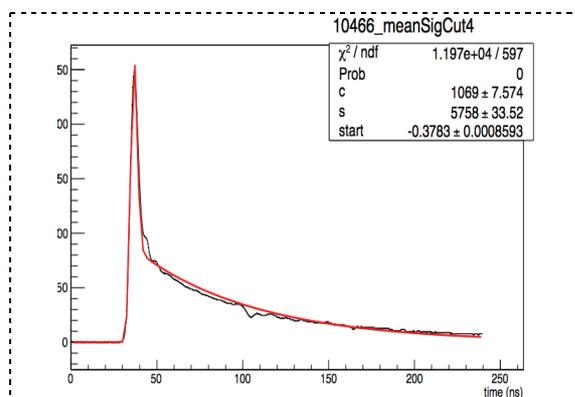


Figure4. Mean signal and simulation with PM “downstream” and glass at Θ_c w.r.t beam

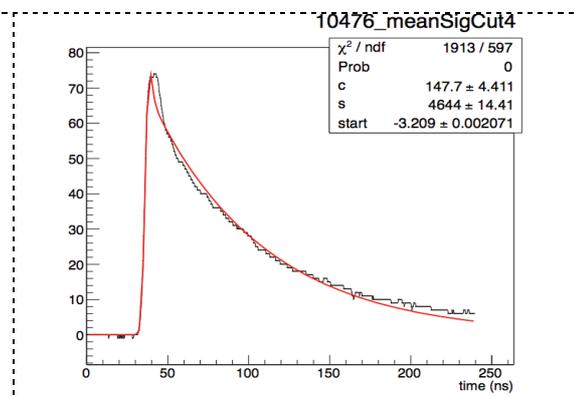


Figure 5. Mean signal and simulation with PM “upstream” and glass at Θ_c w.r.t beam

Measurements were made with both proton and muon beams. With the glass at the Cerenkov angle θ_c (see fig. 3) relative to the beam direction, the responses of all detectors were first measured for different points of incidence of a 120 GeV/c beam. The glass was then rotated by 180 degrees and the process repeated. Mean signals from the EMI PM before and after glass rotation (i.e., with EMI downstream and upstream of beam impact point) are shown in figs. 4 and 5 together with their simulations. Although the simulations still need perfecting, it is clear that, despite a 20% contribution to the signal from hadronic showers (when the glass is oriented at the Cerenkov angle w.r.t. the beam), one will be able to separate the Cherenkov (C) and scintillation (S) signals reliably on the basis of their different time dependence. Scintillatore light output is much smaller (~7%) than that of BGO, which facilitates the separation of C and S components while remaining sufficient for good energy resolution.

With the glass oriented in the beam direction, i.e. “longitudinally” (L), the showering probability increases to ~ 92.7% and, although much of the shower energy escapes the glass, the residual energy still dominates as was confirmed by the distributions of signal integrals (fig.9). Average signals together with fits (in red) obtained using the simulated C and S contributions are shown in figs. 6 & 7. It is evident that a time-based analysis allows for determination of the C/S ratio even in the presence of a predominant hadronic shower contribution to the total energy deposited.

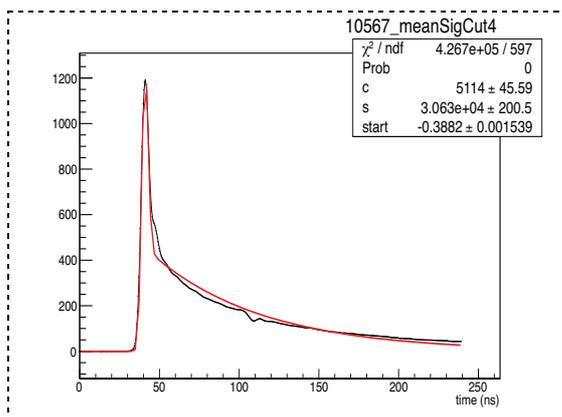


Figure 6. Mean signal and simulation with PM “downstream” and glass // beam.

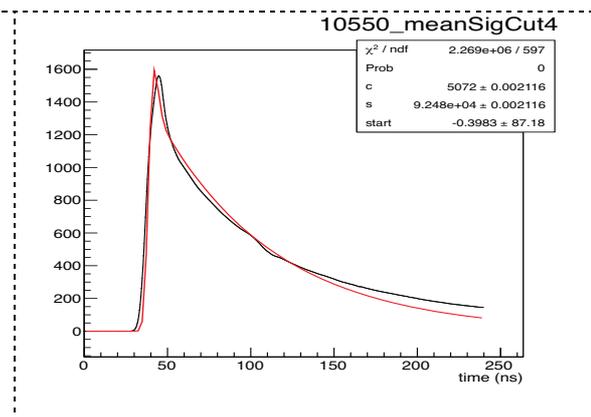


Figure 7. Mean signal and simulation with PM “upstream”, and glass // beam.

The signals from the silicon – based photodetectors show similar characteristics as shown below. However, the bandwidth (<100 MHz) and sampling rate (212 MS/sec) of the TB4 DAQ used to acquire this data were not sufficient for as clean a time-based analysis as was possible for the PM signals with the PM signals to extract C/S. However, there is no reason to expect it will not be possible using the same DAQ as for PMs and this will be verified in future measurements.

On the other hand, the MPPCs were able to resolve the response for different numbers of photoelectrons in the mip peaks, as shown by fig. 8, and this allowed for direct calibration of the light collected by them. After subtraction of the dark count contribution, the light collected per mip by each 3x3 mm² of mppc pad, when the glass was oriented

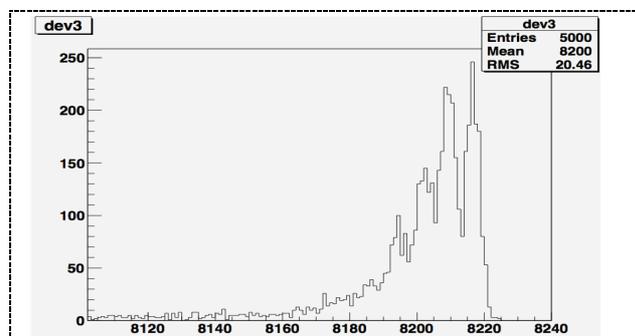


Figure 8 Distribution of signal integrals for mips when the glass is oriented at θ_c w.r.t. the beam direction and the mppc views the downstream end.

at θ_z w.r.t. the beam direction, was found to vary between 0.5 and 1.0 photoelectrons (pe) depending on whether the beam was incident closer to the downstream or upstream end of the glass. With the glass parallel to the beam direction and the mppc viewing the downstream end of the glass, the predominance of shower over mip signals is evident in fig.9. A blow up of the region around the mip peak is shown in fig. 10. After subtraction of the dark count component, the the amount of light collected by one 3×3 mm² mppc pad corresponds to 2.3 pe/mip (1.8 pe/mip with 32 GeV muons).

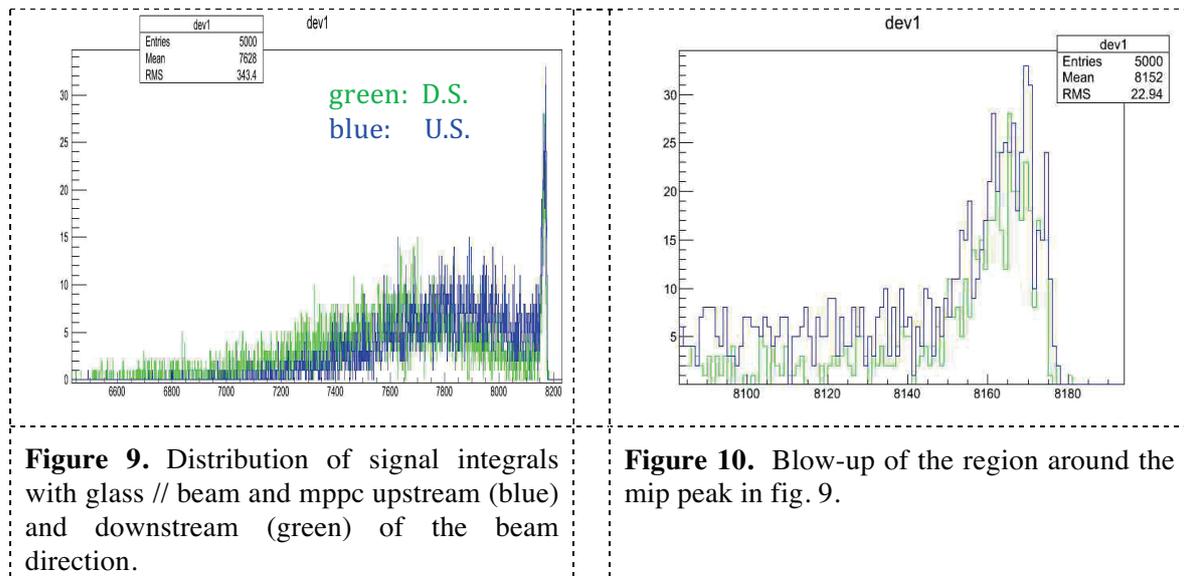


Figure 9. Distribution of signal integrals with glass // beam and mppc upstream (blue) and downstream (green) of the beam direction.

Figure 10. Blow-up of the region around the mip peak in fig. 9.

5. Conclusions

- 1) From a preliminary analysis of data taken with cosmics and particle beams, it appears that the timing characteristics, the C/S ratio ($\sim 10 - 30\%$) and the light output ($\sim 7\%$ BGO) of SCG1-C glass are appropriate for Dual readout Total Absorption Calorimetry.
- 2) The sampling rate of 2.5 GHz used to digitize the PM signals is more than adequate for a time-based off-line separation of C and S components, even when the hadronic shower predominates. Given the circumstances, simple cuts on the signal time distribution would seem sufficient for an on-line DR analysis.
- 3) A 2×2 array of 3×3 mm² silicon, faced up against the glass surface, collects enough light to measure the energy deposition of single mips (for energy calibration) and, with sufficient bandwidth and sampling rate, one will be able to perform the same time-based analysis as for PMs to determine C/S.
- 4) When the thermal noise (dark count) is sufficiently low (below ~ 1 MHz as was the case for the MPPCs), one is able to separate single photoelectrons at the mip level so that the device is auto-calibrating (in photoelectrons). This is an important property for cross-calibration of calorimeter elements and monitoring stability and saturation.

- 5) Analysis of data taken with other conditions and SiPMs is still in progress but it already appears clear that, though they are not heavy enough for use in a compact collider calorimeter, glasses with the SCG1-C characteristics may be used for a test of the principle of Total Absorption Dual Readout Hadron calorimetry, assuming leakage corrections can be reduced to a tolerable level [1]. It also appears that $\sim 1 \text{ cm}^2$ of silicon – based photodetector, faced up against the glass, collects enough light and that it may be substituted for conventional PM.

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