Scintillating Glass for Future HEP Calorimetry

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***Abstract*— A novel homogeneous calorimeter concept is being pursued by CalVision: a collaboration of multiple universities and national laboratories for the proposed high energy physics (HEP) Higgs factory. Dense, UV-transparent and cost-effective inorganic scintillators are required for a longitudinally segmented precision electromagnetic calorimeter (ECAL) with multiple readout. Novel heavy inorganic scintillators, if cost-effective enough, may also be used for a homogeneous hadronic calorimeter (HHCAL) concept which promises a jet mass resolution at a level of 20%/ √E. We report an investigation on cerium-doped aluminoborosilicate (ABS) and cerium-doped DSB ($BaO•2SiO_2$) glass samples. Optical and scintillation properties are characterized at room temperature, including X-ray excited emission, longitudinal and transverse transmittance, pulse height spectrum, light output, decay time, and light response uniformity for long samples. Their emission weighted quantum efficiency (QE) and photon detection efficiency (PDE) are calculated for photomultiplier (PMT) and silicon photomultiplier (SiPM) readouts respectively, and are compared to BGO, BSO and PWO crystals.**

***Index Terms*— Electromagnetic calorimeter, homogeneous hadronic calorimeter, scintillating glasses.**

I. Introduction

CalVision [1] is a novel homogeneous calorimeter concept being pursued by a collaboration of multiple universities and national laboratories for the proposed Higgs factory. It uses multiple measurements, such as scintillation and Cerenkov light and timing information to improve hadronic resolution while maintaining the state-of-the-art electromagnetic resolution. The Caltech HEP Crystal Lab has been working on developing novel inorganic scintillators for precision ECAL and time of flight detectors over the last several decades, and on cost-effective inorganic scintillators in crystal and glass form for the HHCAL concept. Novel inorganic scintillators, if cost-effective enough, may also be used to construct an HHCAL, promising a jet mass resolution at a level of 20%/ √E.

We report result of an investigation on cerium doped aluminoborosilicate (ABS) [2] and DSB ($BaO•2SiO_2$) glass samples [3] for CalVsion. Their optical and scintillation properties are measured, including X-ray excited emission (XEL), longitudinal and transverse transmittance, light attenuation length (LAL), pulse height spectrum (PHS), light output (LO), decay time and light response uniformity for long samples. Nuclear properties as well as emission weighted quantum efficiency (QE) and photon detection efficiency (PDE) are calculated for PMT and SiPM respectively, and are compared to that of BGO, BSO and PWO crystals. The prospect of their use for the HHCAL concept will also be discussed.

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II. Samples and Experiments

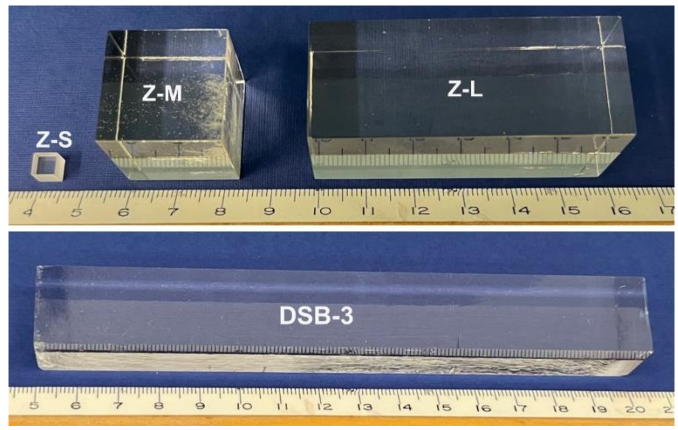

Fig. 1 *Top: Three ABS glass samples: Z-S: a 5 mm cube, Z-M: a 24 mm cube and Z-L: a 25×25×60 mm³ block. Bottom: one DSB sample of 20×20×150 mm³.*

Fig.1 shows some of the samples investigated, including three ABS glass samples (top) and one DSB glass sample (bottom). The ABS samples are provided by the Institute of High Energy Physics (IHEP), and the DSB samples are provided by the 2nd Physics institute of Justus-Liebig University Giessen, Germany. The XEL spectra were measured by using a Hitachi F4500 fluorescence spectrophotometer and an Amptek MINI-X2 miniature X-Ray tube (50 kV). The transmittance spectra were measured by using a Hitachi U-3210 spectrophotometer with double beam, double monochromator and a large sample compartment equipped with a custom Halon coated integrating sphere. The systematic uncertainty is about 0.3% determined by repeated measurements. The scintillation light output and decay kinetics were measured by using a Hamamatsu R2059 PMT, which has a bialkali photocathode and a quartz window. One end of the samples was coupled to the PMT with Dow Corning 200 fluid while all other faces of the sample were wrapped with Tyvek paper. A collimated Na-22 source was used to excite the sample, the output of PMT was readout via an MCA module (LeCroy 3001) with a coincidence trigger. The systematic uncertainty of the LO measurement is about 1%.

III. Results and Discussion

Fig. 2 shows the XEL spectra for three ABS samples (left) and three DSB samples (right). Also shown in the figures are the PMT R2059 QE spectrum and the value of XEL weighted QE (EWQE). The samples were excited at one end by X-rays, and the XEL was measured at the opposite end. The measured XEL thus is light pathlength or sample size dependent. The EWQE values are used to convert light output in p.e./MeV to light yield in photons/MeV. The top plots of Fig. 3 show longitudinal and transverse transmittance (LT and TT) spectra for the long ABS (Z-L, left) and DSB (DSB-3, right) samples. The bottom plots of Fig. 3 show corresponding LAL spectra extracted by using the TT/LT ratio. The numerical value of XEL weighted LAL is about 12 cm for the ABS sample and 23 cm for the DSB sample. Compared to a few meter long EWLAL values of crystal scintillators, the optical quality of glass samples needs to be further improved to match crystal performance.

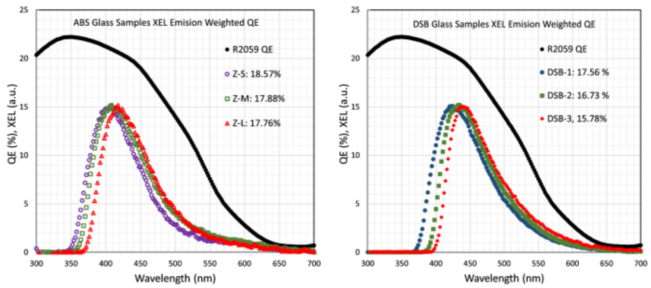

Fig. 2 *XEL and EWQE are shown for 3 ABS (left) and 3 DSB samples (right).*

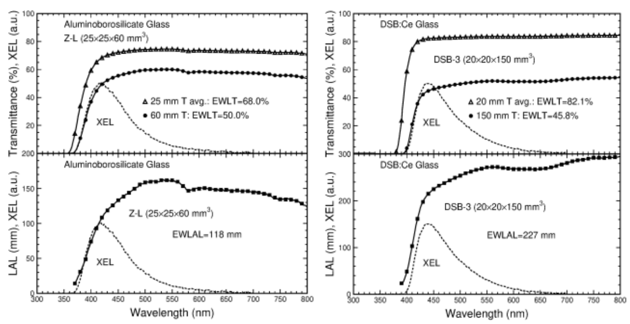

Fig. 3 *Transmittance (top) and LAL (bottom) are shown for Z-L and DSB-3.*

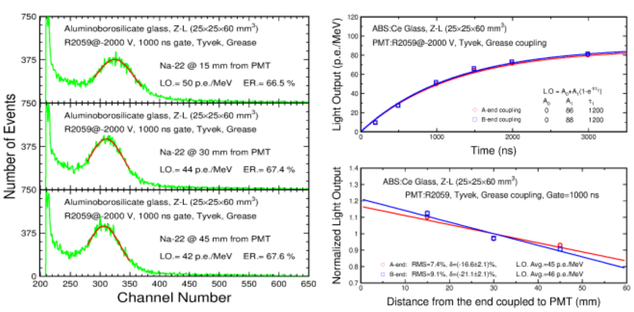

Fig. 4 *PHS (left) and LO as a function of integration time (top, right) and as a function of exciting position (bottom, right) with 1µs integration time for Z-L.*

The left plot of Fig. 4 shows the PHS measured with a Na-22 source exciting along the sample Z-L at 15, 30 and 45 mm from the R2059 PMT. The top right plot shows LO as a function of the integration time measured with a Na-22 source at 15 mm from the PMT for the sample Z-L with two alternative ends coupled to PMT. The consistent LO and decay time of 1.2 µs imply that the sample has adequate uniformity. The bottom right plot shows the normalized LO as function of the Na-22 excitation position with two alternative ends coupled to the PMT. The rms value of 7~9% may be further improved with increased LAL. The corresponding results for the 120 mm long DSB-3 sample are shown in Fig. 5.

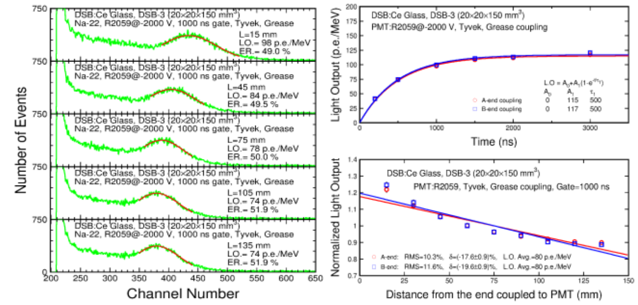

Fig. 5 4 *PHS (left) and LO as a function of integration time (top, right) and of exciting position (bottom, right) with 1µs integration time for DSB-3.*

Table I lists scintillation performance and nuclear property for ABS Z-L and DSB-3, and compared to BGO, BSO and PWO crystals of $1.5X_0$ cubes. With density as high as 6 g/cm^3, inorganic scintillators in glass form are promising for the HHCAL concept for the proposed Higgs factory.

TABLE I

COMPARISON OF ABS AND DSB SAMPLES WITH BGO, BSO AND PWO

Parameter	BGO	BSO	PWO	ABS (Z-L)	DSB (DSB-3)
Dimensions (mm^3)	17^2×17	17^2×17	13^2×13	25^2×60	20^2×150
Density (g/cm^3)	7.1	6.8	8.3	6.0	4.3
X_0 (cm)	1.12	1.15	0.89	1.55	2.58
λ_I (cm)	22.7	23.4	20.7	24.7	30.9
XEL Peak (nm)	480	480	428	416	438
Decay time (ns)	312	94	30	1200	500
EWQE (%)*	13.0	13.0	18.5	17.8	15.8
E.R. for 511 keV (%)*	16.7	34.9	86.5	66.2	50.5
LO (p.e./MeV)*	760	152	23	87	116
LO/EWQE* (ph./MeV)	5846	1169	124	490	735
EWPDE (%)**	31.8	31.8	28.6	29.0	31.9

X_0: radiation length, λ_I: interaction length, * PMT: R2059, **SiPM: s14160-3015ps.

IV. SUMMARY

An ABS glass sample of 6 cm long and a DSB glass sample of 15 cm long were measured at Caltech. While both samples show an adequate light response uniformity, the DSB sample is faster, brighter and more uniform than the ABS sample. The ABS, however, appears more promising for the HHCAL detector concept because of its high density of 6 g/cm^3. R&D will continue to investigate bright, fast and cost-effective heavy inorganic scintillators in crystal and glass form for CalVision.

REFERENCES

[1] CalVision Collaboration, https://detectors.fnal.gov/projects/calvision/.

[2] G. Tang et. al., Optical Materials 130 (2022) 112585.

[3] R. W. Novotny et. al., 2019 J. Phys.: Conf. Ser. 1162 012023.