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Performance of GlueX-BCAL 'first-article' scintillating fibres

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Abstract

The response of Kuraray SCSF-78MJ (blue-green) scintillating fibres was measured using a 373-nm UV LED and independently using a ^{90}Sr radioactive source. The former measurements yielded the spectral response as a function of wavelength that allowed the determination of the bulk attenuation of the fibres, folded with the wavelength response from a typical bi-alkali photo multiplier. The later resulted in the extraction of the number of photoelectrons at 200 cm along the fibre's length, using a calibrated silicon photomultiplier. Both sets of results confirm that these fibres meet the GlueX specifications as contracted to Kuraray and, therefore, signal the start of production of Fibres towards the construction of the GlueX barrel calorimeter.

Key words: scintillating fibres, wavelength response, photoelectrons, optical transmission, electromagnetic calorimeter
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1 Introduction

The study in this paper was undertaken in the context of determining whether the SCSF-78MJ scintillating fibres provided by Kuraray to GlueX meet the

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specifications as layed out in the contract. Specifically, the key parameters tested and reported herein are a) spectral response (wavelength of maximum emission between 450-500 nm), b) the bulk attenuation length (greater than 250 cm for a bare fibre, and greater than 300 cm when measured with a bi-alkali photomultiplier tube - PMT), and c) the light output, quantified as the number of photoelectrons collected at the fibre's end (greater than 3.5 p.e. using a bi-alkali PMT at 200 cm from the source. Other parameters were dimensional uniformity, cladding thickness, time structure and base material components, but these are not reported here.

2 Project Background

The production fibres are to be coupled to the electronic front-end readout of the electro-magnetic barrel calorimeter (BCAL) for the GlueX project [1,2]. The BCAL is a sampling calorimeter based on scintillating fibres and will be deployed inside the GlueX detector's super-conducting solenoid. The central field of the solenoid is 2.2 T, resulting in substantial magnetic field strength and gradients near the BCAL ends, so using vacuum PMT's with short light guides is not possible.

The BCAL will be comprised of a lead and scintillating fibre matrix, consisting of ∼200 layers of lead sheets, each of 0.5 mm thickness, and 1-mm-diameter, multi-clad, scintillating fibres (SciFi), bonded in place using BC-600 optical epoxy [1]. This geometry results in ∼16 000 Fibres per module. The detector will consist of 48 modules each ∼ 4 cm long and with a trapezoidal cross section, and will form a cylindrical shell with inner and outer radii of 65 cm and 90 cm, respectively. In fall 2008, after a tendering process, the Fibre contract was awarded to Kuraray [3].

The chemical and optical properties of scintillating materials have been presented elsewhere [4–6]. Such materials are composed of a chemical base, usually polystyrene or polyvinyltoluene, and one or more dyes that are added to improve the quantum yield of the scintillator and to waveshift the scintillation light to longer wavelengths. Typical absorption and emission spectra and their relation to our UV LED can be found in our past work [7].

[1] St. Gobain Crystals & Detectors, Hiram, OH 44234, USA (www.bicron.com)

3 Measurements

3.1 Spectral Response and Bulk Attenuation

3.1.1 Experimental Setup

For the measurements reported herein, a LED light source, a spectro photometer and the tested SciFi were coupled together in a robust and reproducible manner. A USB4000 single-channel fibre optic spectro-photometer [2] is based on a blazed diffraction grating with a 50 μm wide slit and features a high-sensitivity 3648-element linear CCD array that provides high response and excellent optical resolution from 200-1100 nm and a 16 bit A/D. This device had been calibrated by the manufacturer, and the provided specifications indicated a wavelength difference, $|\delta\lambda|$, between expected and measured values, never exceeding 0.3 nm for any given pixel on the CCD. The USB2000 is connected to a PC running commercial software via a USB2.0 interface. The spectro-photometer has a maximum integration window of 3.8 ms and with a resolution of $\sim$3.3 bins/nm (or 0.3 nm).

For our measurements, a RLU370-1.7-30 ultra violet LED [3] was employed, with a peak emission wavelength of 373 nm, a spectrum bandwidth of 13 nm, and typical radiant flux of 1.7 mW. Past tests [7] had demonstrated that these spectro-photometers are correctly calibrated versus wavelength by its manufacturer and that there is no significant contribution from the light source to the intensity of the measured fibre spectra in the wavelength range of interest.

Each fibre was first cleaned using alcohol and Kim wipes and was handled using white cotton gloves. The test Fibre was then positioned horizontally in a 4-m long 1-mm-deep channel, machined in a black poly-ethylene bar ("puck board" material), that had a measuring scale attached on one of its long sides.

The first (Fibre Cane 2-33) test fibre's end was successively rough cut near its tag, polished and blackened using black mat enamel paint (used for scale model painting). Measurements were taken at all three configurations and showed that the bulk attenuation decreased after each step, resulting in the blackened end having the lowest value due to elimination of reflections. From then on, the far end of all fibres was polished and blackened.

The near fibre end of the fibre was polished using a Fibre Fin 4 diamond polisher [4] and then threaded through a BFA-SMA connector mounted on an

[2] Ocean Optics Inc., Dunedin, FL, USA (www.oceanoptics.com)
[3] Roithner Lasertechnik,Vienna, Austria (www.roithner-laser.com)
[4] FibreFin Inc. 201 Beaver Street, Yorkville, IL 60560 USA

Ocean Optics BFA-KIT custom chuck, that allowed the fibre's end to be placed flush with the SMA end, while held in place with a rubber-lined clamp. The SMA end was connected to the USB4000 input. In it interior lies a short-length Fibre that illuminates the CCD while its other end is placed in direct contact with the Kuraray test fibre with an air gap between them. This method allowed for fast and easy and coupling of fibre to spectro photometer, although the coupling reproducibility varied, a feature that does not affect the extraction of the bulk attenuation length but only the absolute light output that was not extracted using this method. The setup was made robust to protect against displacing the test fibre and was leveled to avoid any curvature in the test fibres.

The LED was installed in a commercial housing and was mounted on a custom-design fixture that could slide on the lab bench guided by the puck board, and translated across the length of the fibre (from 10 cm to 400 cm in 10 cm steps). It should be noted that the distance of the LED to each fibre tested was held constant to maintain a consistent beam profile; however, the resulting profile was narrow and may have resulted in a small non-uniform illumination of the fibre are different positions along its length, owing to the manner in which the mount "fit" across the puck board. This effect and the Fibre coupling reproducibility mean that absolute comparisons of the measured intensity from one fibre to another were not possible. Nevertheless, relative comparisons of the measured light intensity along the length of a given fibre were possible, since the spectral shapes and bulk attenuation are insensitive to these non-uniformities and this could be extracted reliably.

All measurements were carried out in near darkness in our lab, employing a small desk lamp to provide ambient light. However, since the core of blue-emitting scintillating fibres can be damaged by prolonged exposure to UV light, yellow, UV-absorbing film (TA-81-XSR [5]) was used to cover all overhead fluorescent lights and the desk lamp during the preparation and setup stages.

3.1.2 Results

The bulk attenuation was extracted in two different manners: a) the number of counts in each wavelength bin was summed up over the wavelength range, yielding a single number at each distance, and b) the spectra were integrated using a Moyal function:

$$f(x, a, \mu, \sigma, b) = a \cdot \exp\left(-\frac{1}{2}\left(\frac{(\lambda-\mu)}{\sigma} + e^{-(\lambda-\mu)/\sigma}\right)\right). \qquad (1)$$

[5] Window Film Systems, London, ON, Canada (www.windowfilmsystems.com)

In both cases, the resulting sum/fit was plotted versus distance and a single exponential was fit over the 100-285 cm range, to compare to Kuraray's standard method of bulk attenuation extraction. Along this vein, the spectra were convoluted by an approximation to the quantum efficiency of a bi-alkali photocathode.

The spectra required a sum of two Moyal [8] functions plus a flat background. The Moyal distribution is often used as a good approximation to the Landau distribution [8], and was chosen here as the description with the fewest fit parameters; in any case, it was employed simply as a tool to integrate the spectra and proceed further in the analysis.

The fibre spectra of intensity versus wavelength were convoluted over wavelength with the spectral integral of a typical bi-alkali PMT shown in Fig. 1 in order to more directly compare the results to those extracted by Kuraray, in which the current is measured off a similar PMT. The parametrization shown in this figure followed this equation:

$$I_{scaled} = \frac{I}{4} \times \exp[\frac{1}{2}\frac{(\lambda - 400\,nm)^2}{(80\,nm)^2}] \quad (2)$$

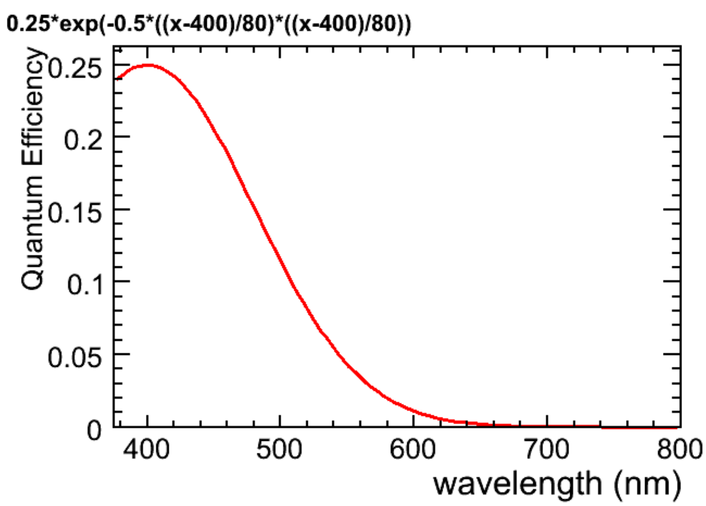

Fig. 1. Quantum efficiency parametrization versus wavelength, using Eq. 2. This curve was folded with the raw data to produce spectra more directly comparable to those of Kuraray.

Raw and PMT-scaled sample spectra at 10 cm, 100 cm and 300 cm are shown in Fig. 2 together with their corresponding Moyal fits.

The Moyal fits described above were integrated over wavelength for the fibres for various source distances and fitted by a double exponential. A sample fitted spectrum is shown in Fig. 3.

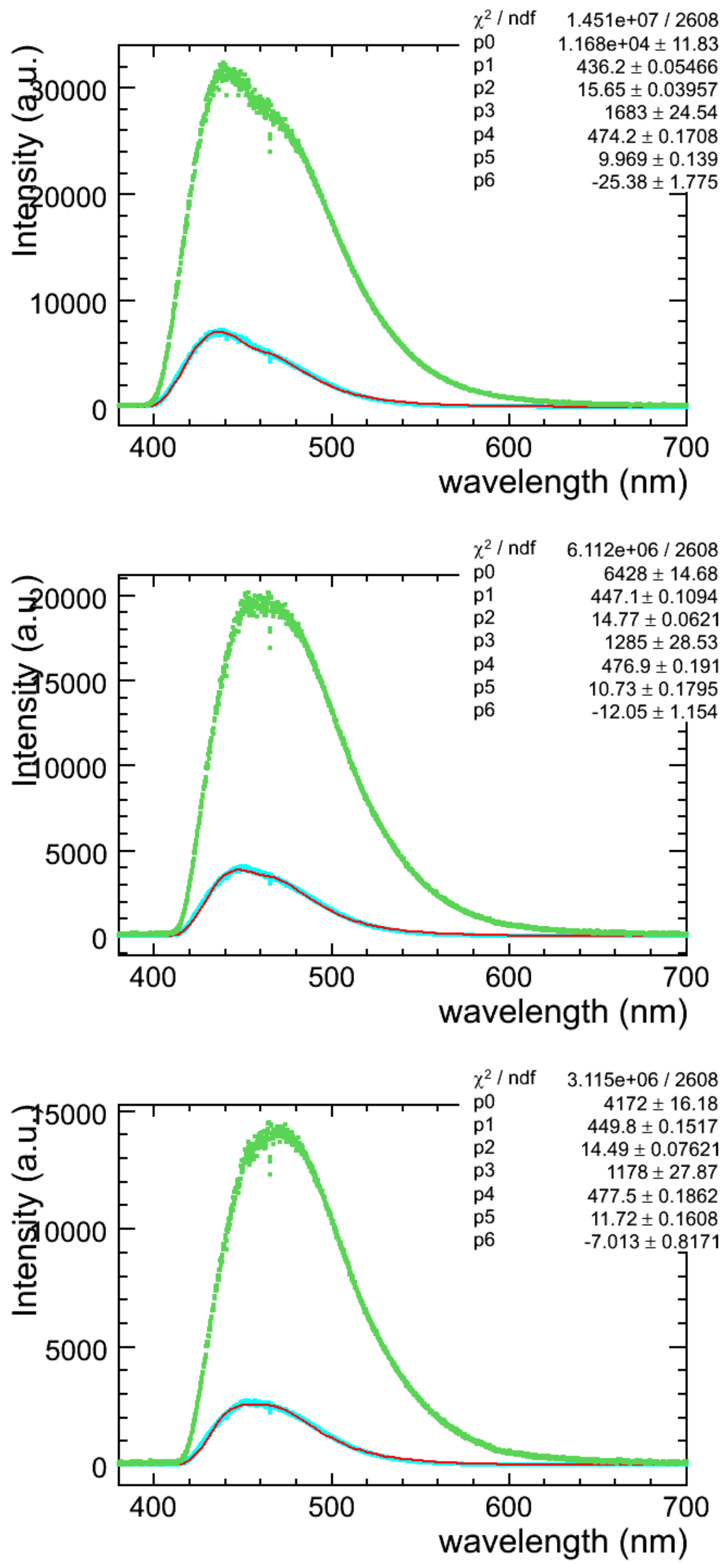

Fig. 2. The green data points are the raw spectra as seen by the photo-spectrometer. The light blue points are scaled by an approximation to the quantum efficiency of a bi-slkali photocathode. The fit functions were of the double Moyal type.

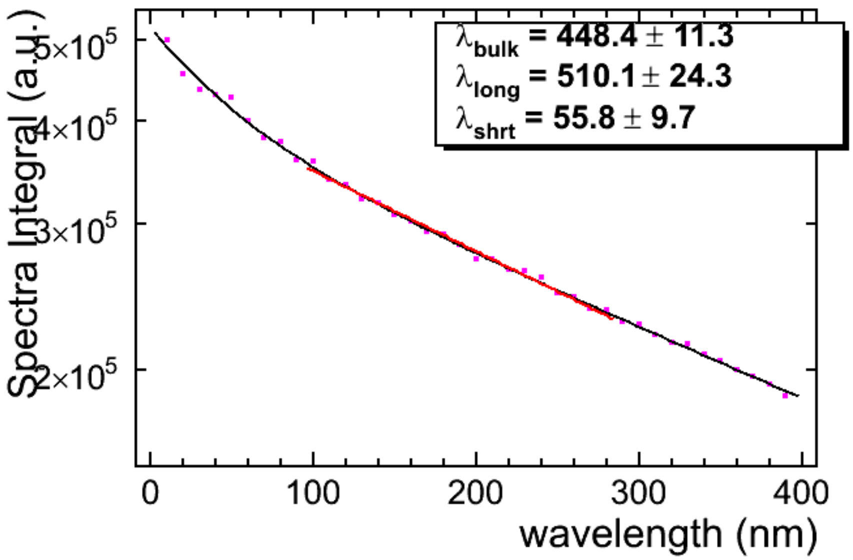

Fig. 3. Integrals of the Moyal fits to the fitted data are plotted as a function of source distance for Fibre 09-3. The curve is a results of a fit to a double exponential (shown in black). The bulk attenuation was extracted over the distance range of interest (shown in red), as specified by Kuraray. The legend shows it as well as the short and long attenuation components found using a double exponential fit.

The results from measurements of 11 fibres are shown in table 1. These results demonstrate consistency between the Moyal fitting and bin summing methods. They are consistently higher than the Kuraray results, which is primarily – but not exclusively – due to the assumption made in this work on the photosensor quantum efficiency that is likely quite different than that used by Kuraray. It appears that our assumption involves and overall factor of 15-20% relative to the Kuraray results.

"Micro-features" appeared in the spectra of some fibres, resembling a small, periodic, oscillator behaviour over certain distance ranges. To investigate such features further, measurements were taken of the same fibre on different days and by detaching and re-coupling the fibre before the second measurement. Similar features showed up in both measurements but did not appear in other attenuation spectra. This suggests that there are features within the fibre smaller than 10 cm that affect the light output at that point on the fibre. This may be a crack in the core of the fibre or possibly a change in the doping in that region or stresses in the polystyrene due to the extrusion process. Notwithstanding, the results on the bulk attenuation were robust and did not depend on these features, that points to the stability and repeatability of the measuring process within coupling tolerances. These effects will be investigated further in future measurements, together with additional cross checks. It is expected that future findings will not affect the outcome of this study.

	Moyal Fits		Sum of Bins		Kuraray
Fibre Cane	λ	$\delta\lambda$	λ	$\delta\lambda$	λ
	(cm)	(cm)	(cm)	(cm)	(cm)
01-3	440	13	442.3	8.7	368.0
02-3	435	12	N/A	N/A	330.7
04-3	428	6	N/A	N/A	367.5
05-3	417	9	N/A	N/A	366.6
07-3	464	8	N/A	N/A	351.6
09-3	448	11	N/A	N/A	390.0
23-2	443	10	445.6	9.0	369.1
26-2	478	9	477.1	9.6	374.8
32-2	414	10	451.5	9.6	377.5
33-2	398	15	409.4	7.3	385.4
49-3	441	12	443.5	8.8	377.4
Average	437	10	445	9	369

Table 1
Bulk attenuation length extracted using the Moyal fit method and bin summing. Also shown are the Kuraray measurements for these specific fibres. Details can be found in the text.

3.2 Number of photoelectrons

3.2.1 Experimental Setup

Four of the fibres measured using the spectro photometer were then transferred to a separate measuring station. Each fibre had its blackened end cut off and repolished. The fibres were successively placed in a 4.5-m-long dark box. One end was coupled to a Hamamatsu RC 329-02 calibrated photomultiplier and the other to a SensL[6] silicon photomultipier (SiPM) having a 3×3 mm active area and based on the A20HD microcell. This particular SiPM had been previously calibrated with respect to its photon detection efficiency (PDE) versus a calibrated Hamamatsu photodiode (see reference [9]). The PDE was determined to by 9% at an overbias of 3 V, the operating condition in these tests. The PMT was set to 1700 V. Both fibre ends were coupled using optical grease.

During the tests, a ^{90}Sr radioactive source placed on a collimator was located

[6] SensL, Blackrock, Cork, Ireland (www.sensl.com)

over the near centre point of the Fibre and approximately 200 cm from the SiPM end. The PMT set the trigger of the data acquisition. Details of the source collimation are shown in reference [9].

3.2.2 Results

The collected ADC spectra clearly showed individual photoelectron peaks up to 11 in number. A typical raw spectrum is shown in the top panel of Fig. 4. The middle panel in this figure shows the pedestal as extracted by having the SiPM and its amplifier on but after having removed the ^{90}Sr source. The bottom panel shows the pedestal-subtracted spectrum and the multi-parameter fit, based on Gaussian distributions, to extract the number of photoelectrons.

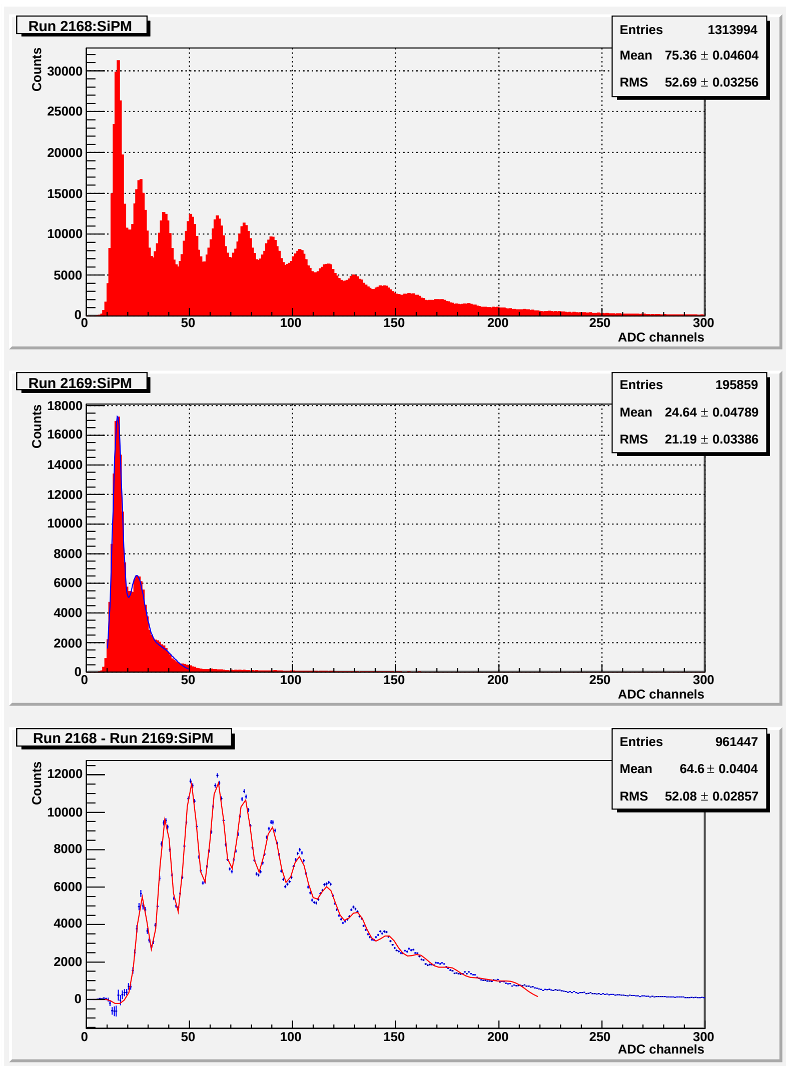

Fig. 4. Raw ADC spectrum (top), pedestal spectrum (middle) and subtracted spectrum and fits (bottom). Details are provided in the text.

The results for the four measured fibres are tabulated below 2.

Fibre Cane	Number of p.e.	Error
09-3	5.96	0.12
26-2	5.98	0.11
33-2	5.51	0.08
49-3	5.65	0.10
Average	5.78	0.10

Table 2
Number of photoelectrons extracted.

4 Summary and Conclusions

The objective of this study was to examine three of the most important parameters of Kuraray SCSF-78MJ scintillating optical fibres, namely the spectral shape, bulk attenuation length and number of photoelectrons.

The spectral shape was as expected, based on past measurements and experience of similar types of fibres. The average bulk attenuation of the fibres, after convolution with a photosensor quantum efficiency, was over 400 cm. The number of photoelectrons at 200 cm was above 5 p.e. and after correction from a SiPM to a PMT would increase further. Clearly, all tested fibres meet or exceed the contract conditions to Kuraray.

Further tests are underway of additional fibres and to study other effects. Moreover, a length scan of fibres will be carried out using the ^{90}Sr source in the near future.

5 Acknowledgments

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