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Quality of scintillating fibres after hot bump shrinking

SciFi Project

A.B. Cavalcante[1], L. Gavardi[2], C. Joram[3]

[1] Centro Brasileiro de Pesquisas Físicas (CBPF), Rio de Janeiro, Brazil

[2] Technical University Dortmund, Germany

[3] CERN / EP Department

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Abstract

Shrinking the diameter of fibre bumps by a hot drawing tool requires to run the fibre through the hot tool over its full length, bearing the risk of a degradation of the fibre performance. In this study we demonstrated that the hot bump shrinking method has no visible effect on the optical attenuation length, the light yield following ionising radiation, the diameter, the mechanical stability and the integrity of the cladding. For the latter, even a small positive impact was observed.

1. Introduction

The SciFi tracker will be based on round SCSF-78 scintillating fibres of 0.25 mm diameter. The fibres, as delivered by the supplier, show a certain diameter variations, referred to as bumps and necks, which potentially compromise the pattern, when such fibres are wound to staggered multi-layer mats.

Recently, a method was proposed, which is alternative to the cutting and re-joining methods used so far. The method consists in drawing the fibre through a hot drawing tool (see Figure 1) with a conical hole of d1 = 0.35 mm minimum diameter. The tool is kept at a constant temperature of about 100°C. Fibre bumps exceeding 0.35 mm get temporarily stuck in the conical hole. Within a few seconds the contact region of the fibre heats up and softens, such that it creeps under the pull force of about 100 cN through the hole, reducing the maximum fibre diameter to about 0.35 mm.

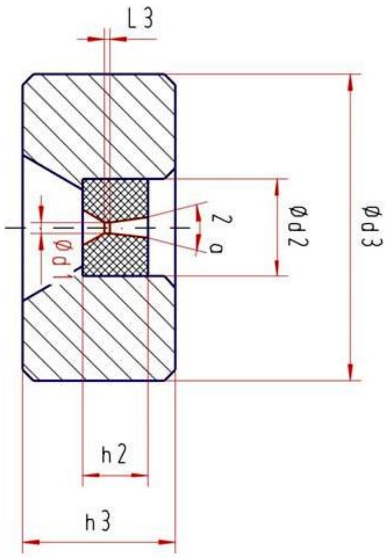


Figure 1: Geometry of the drawing tool. The drawing direction is from right to left.

The method implies that the complete fibre (i.e. the full 12500 m length of a spool) passes through the hot tool. During most of the time the fibre passes at relatively high speed of about 1 m/s. The region of about 1 m before and after the bump passes at a speed of about 15 cm/s. Even if the tool is well aligned to the theoretical fibre axis, it cannot be excluded that the fibre touches the hot tool wall as the nominal clearance is only 50 μm. The length of the contact zone L3 is of the order 1 mm, i.e. the contact time at the slow speed of 15 cm/s is below 10 ms.

Before applying the bump shrinking method during the series production of the fibres (11'000 km), any negative impact from the mechanical contact with the tool and the temporary heating on the fibre properties must be excluded. The critical fibre quantities are the attenuation length and the light yield following ionising radiation. Both could degrade from overheating the fibre. Furthermore, the integrity of the 2 x 7.5 μm thick cladding structure which could be affected by scratches or detaching from the core. This would lead at the same time to a change of the fibre diameter. Lastly, the mechanical stability of the fibre could degrade due to thermal or geometrical effects.

In the following we present a set of measurements which addresses each of the points.

2. Attenuation Length

The typical attenuation length of the SCSF-78 fibres of 0.25 mm diameter, as measured in the set-up at CERN [1], is between 3 and 3.5 m. Fibres are known to degrade at elevated temperature (> 60°C) due to oxidation effects. Conservative estimates of the possible temperature increase assuming permanent contact with the hole wall remain far below this limit but also have large uncertainties. Touching the fibre which has just passed the hole, even at a very low speed of 3 cm/s, does not hint at any noticeable temperature increase.

We have measured the attenuation length of a 20 m long section of fibre, taken from the batch CE-160229-1. Three 3 m long samples were cut off and measured as taken from the spool (without passing through the hot tool). The remaining part of the section was then pulled through the drawing tool, maintained constantly at 100 ± 1°C. Two drawing speeds were used: 15 cm/s and 3 cm/s. Two sets of three 3 m long samples, corresponding to the sections with the two speeds were analysed. The results of the attenuation length measurements are summarised in Figure 2. The attenuation plots of the individual fibres are shown in the appendix A.

Within the uncertainty of the method, all measured samples show identical attenuation length, independent whether they have passed the tool or not and at which speed.

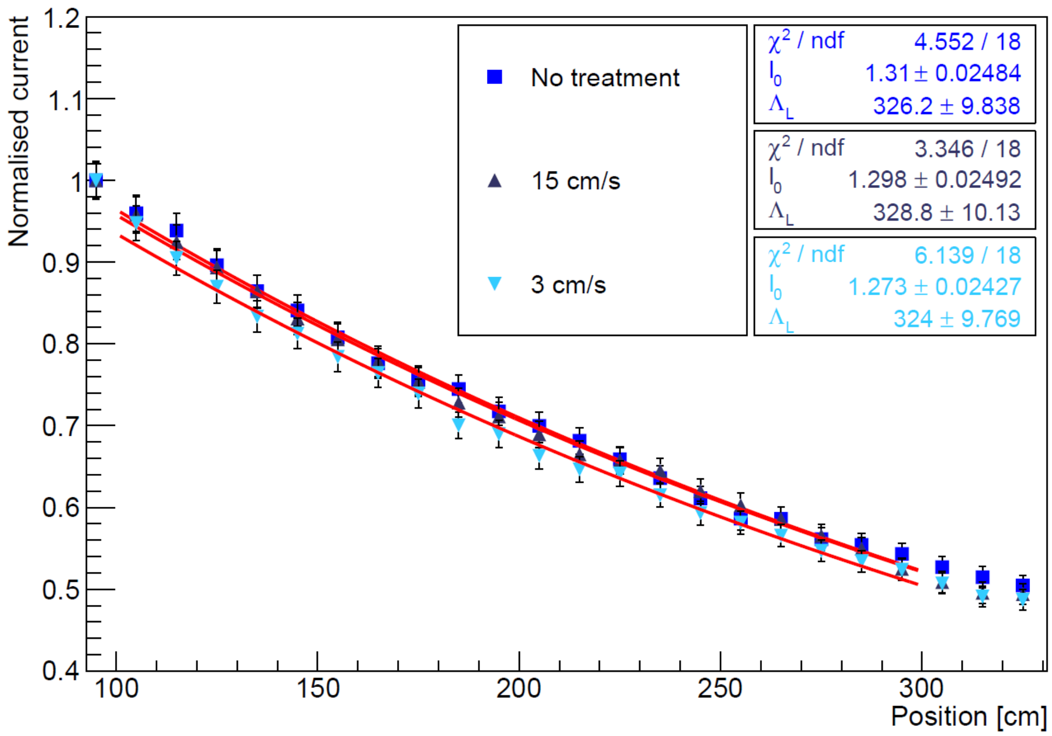


Figure 2: Averaged light attenuation of the three investigated fibre sets. The attenuation length Λ_L is determined by a single exponential fit to the data between 100 and 300 cm from the photodetector. The three data sets refer to the untreated fibres and the two drawing speeds of 3 and 15 cm/s. All three sets show identical values around 325 cm.

3. Light yield following ionising radiation

The light yield of a set of 3 scintillating fibres is measured with a dedicated set-up at CERN [2]. The fibres are mounted vertically aligned on top of each other and exposed to electrons of 1 MeV energy from an energy filtered Sr-90 source. The 3 fibres are jointly read out by a Hamamatsu SiPM detector. The distance d between the source and the readout end are varied between 90 and 240 cm, which allows to extrapolate back to zero distance. Typically, (untreated) SCSF-78 fibres, show in this configuration a yield of 12 to 13 photoelectrons, extrapolated to d = 0.

A 15 m long section of fibre from spool CE-160229-1 was run through the hot drawing tool at a speed of about 3 cm/s. The fibre was then cut in 3 pieces of about 3 m length, which were mounted in the light yield set-up as described above. The result of the test is shown in Figure 3. With 13.1 photoelectrons it is fully compatible with the untreated SCSF-78 fibres.

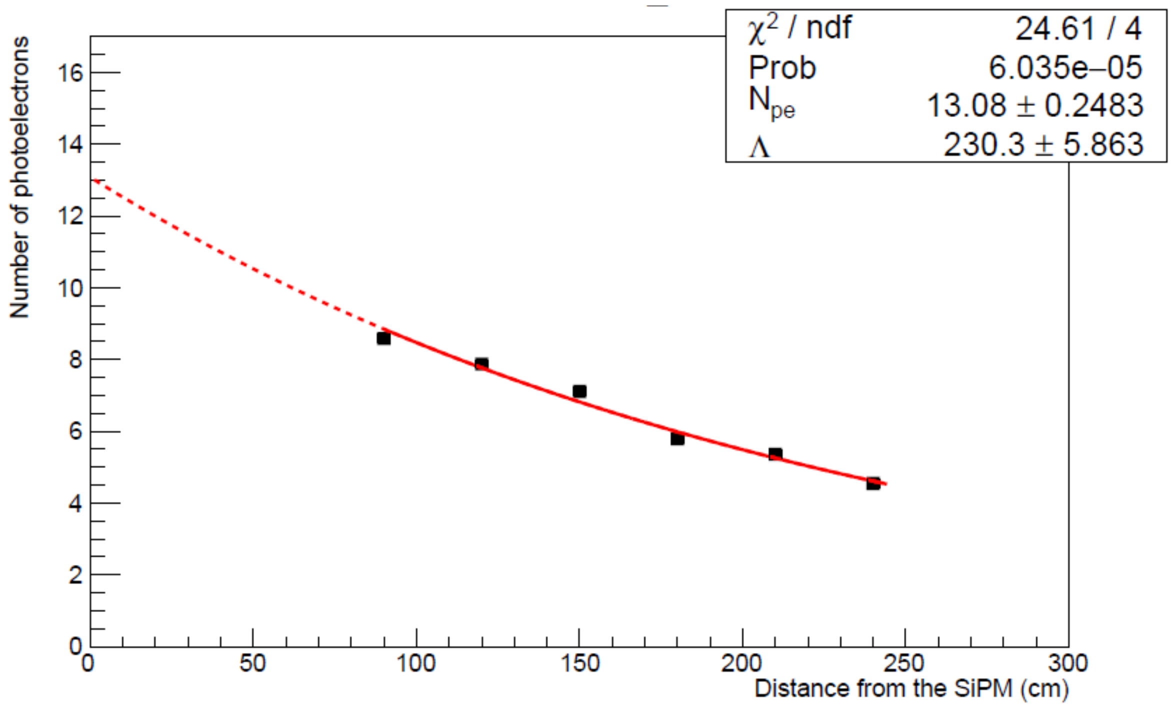


Figure 3: Light yield versus distance from the Sr-90 source for fibre CE160229-1 after passing through the hot tool at a speed of 3 cm/s. The light yield extrapolated to d = 0 results in 13.1 photoelectrons.

4. Integrity of the cladding structure and fibre diameter

The integrity of the cladding is tested using the fibre diameter scanner at CERN [3]. The fibre passes through the dark cladding test box, in which it is locally excited by a UV LED. About 60 cm downstream, the fibre passes through a spherical measurement cell, in which light 'leaking' from the fibre is detected by a SiPM detector. The signal is sampled and read at a rate of 2400 Hz, together with the diameter measurements in the two orthogonal directions.

A hypothetical perfect fibre with a perfect outer surface, would not emit any light at a distance of 60 cm from the excitation point. Non-trapped light emerging from the fibre is primarily due to an imperfect cladding-air interface. Surface roughness and defects like scratches or little holes allow light which travels in the cladding to leave the fibre. A small amount of light escapes due to (Rayleigh) scattering in the fibre core. Long-range variations of the fibre diameter are recognisable as a baseline modulation of the detected signal. The baseline can also be slightly affected by the ambient light level in the lab, as the fibre is exposed to it before and after entering into the cladding test box. The following measurements were therefore performed in the evening. The neon tubes, equipped with UV blocking films, have negligible impact on the cladding test signal.

A sample of 110 m fibre length from spool CE-160229-1 was run at a speed of 15 cm/s through the fibre scanner. The fibre drawing tool was not in place. Diameter and cladding test information was recorded. The fibre was then run in reverse direction at a speed of 15 cm/s for 80 m and at a speed of 3 cm/s for the last 20 m through the scanner with the hot (100°C) drawing tool in place. Finally, the fibre was again run through the fibre scanner, in the same direction and at the same speed as during the first run, recording again diameter and cladding test information.

Figure 4 shows the cladding test signal obtained in this measurement. The data (blue) before the passage of the drawing tool has been shifted up by 10 mV for better clarity. After the passage, the average signal and its fluctuation is slightly reduced. The needle-like structures which occur in the blue curve typically once per meter, are significantly reduced in number and amplitude.

Figure 5 shows the fibre diameter measurements before and after running the fibre through the hot drawing tool at low and medium speed. The shown diameter is the average of the two orthogonal directions. The statistical analysis shows that the average diameter and the RMS values are essentially unchanged.

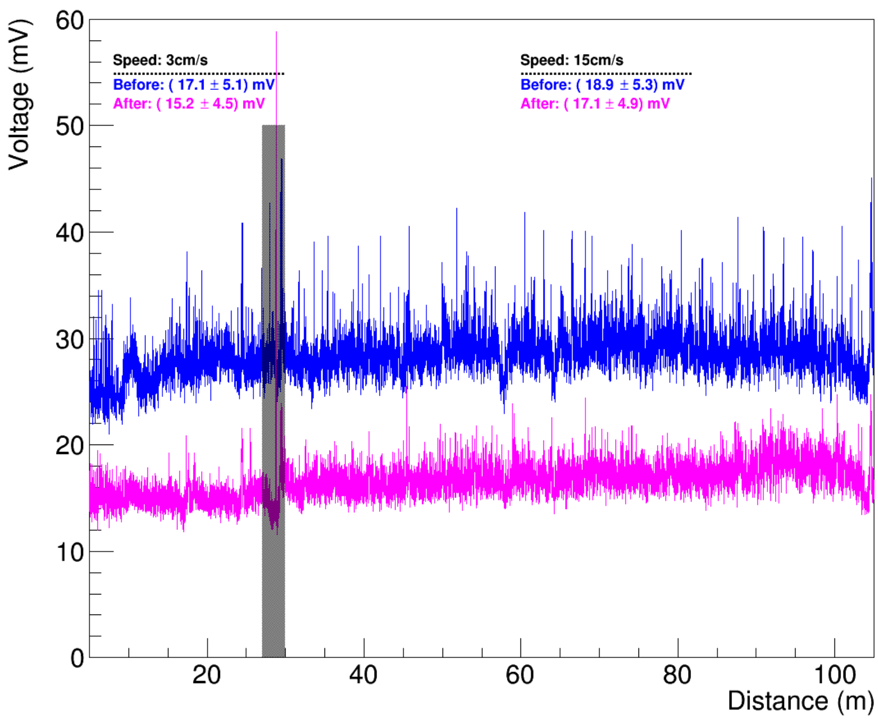


Figure 4: Cladding test signal versus fibre position for slow and medium speed passage of the hot tool. The blue curve, taken before the passage through the drawing tool, was shifted up by 10 mV for better clarity. The magenta curve was obtained after the passage. The grey bar indicates the transition from low (3 cm/s) to medium (15 cm/s) drawing speed.

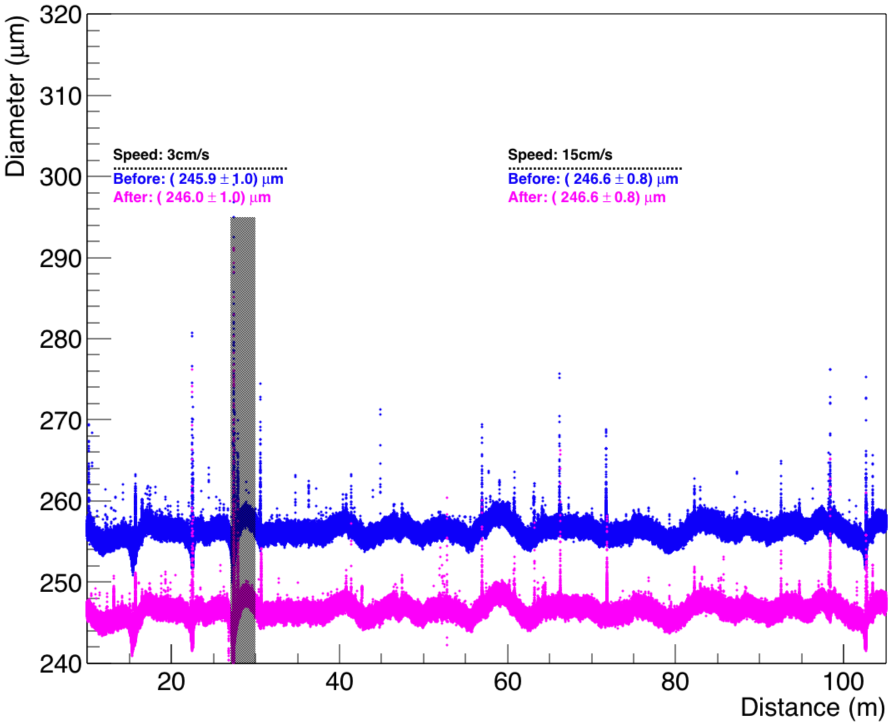


Figure 5: Fibre diameter measurement before (blue) and after (magenta) running the fibre through the hot tool at low and medium speed. The blue curve has been shifted up by 10 (µm) for better clarity. Mean values and RMS are essentially unaffected.

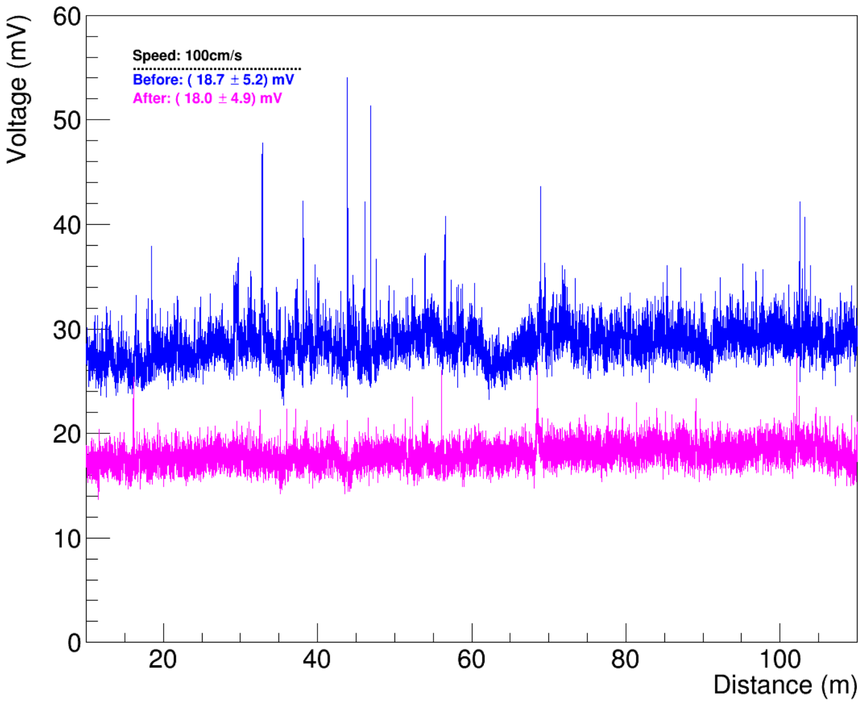


Figure 6: Cladding test signal versus fibre position for high speed passage of the hot tool. As above, the blue curve is shifted up by 10 mV. The measurement 'after' (magenta) has a slightly lower average and RMS.

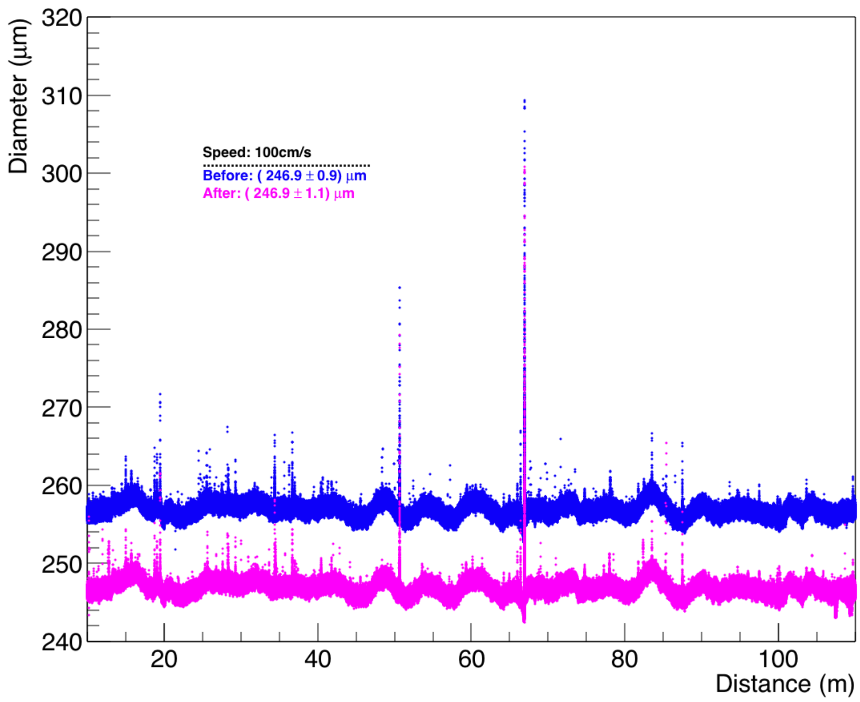


Figure 7: Fibre diameter measurement before (blue) and after (magenta) running the fibre through the hot tool at high speed. Mean value and RMS are very similar.

The complete sequence was repeated with another 110 m sample from the same spool. In this test, the fibre was run through the hot drawing tool at the nominal scan speed of about 100 cm/s (speed regulator on 85%). The measurement runs before and after were again performed at 15 cm/s.

Figure 6 and Figure 7 show the results of the test. Also at the high speed of 100 cm/s the passage through the drawing tool slightly reduces the amount of detected light and its fluctuations, however the statistical analysis of average and RMS shows that the effect is smaller.

In summary, the above cladding tests results have shown for all three investigated speeds a small but systematic reduction of the average signal and its fluctuations. The reduction is slightly more pronounced at lower drawing speeds, i.e. longer contact time. It is conceivable and plausible but hard to prove, that the passage through the hot drawing tool slightly smoothens the fibre surface and therefore reduces the amount of escaping cladding light. The diameter, both average and RMS, is not affected.

5. Mechanical stability

The nine fibre samples used for the attenuation length measurements were also used for pull tests up to fibre breakage. The tests were performed using a mechanical fine-scale force gauge with 10 cN resolution. The fibre piece to be tested was attached at one end to a fibre spool of 210 mm inner diameter. The other end was attached with an adhesive tape to the force gauge. The gauge slowly pulled down, ensuring vertical alignment of the fibre, until breakage occurred. The fibre broke somewhere in between the touch point on the spool and the tape fixation. In all cases breakage occurred around 220 ± 10 cN, independent whether the samples have passed the tool or not and at which speed.

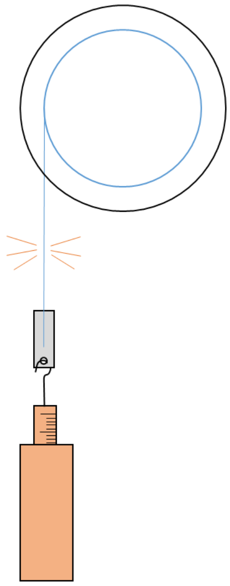


Figure 8: Illustration of the force measurement.

6. Summary and conclusions

Samples of the fibre CE160229-1 were tested in terms of optical attenuation length, light yield, diameter, mechanical stability and integrity of the cladding after having passed the hot bump shrinking tool. In most cases the speed at which the fibre passed through the tool was reduced from the normal 100 cm/s to 15 or even 3 cm/s which potentially increases the effect of the hot tool on the fibre. None of the measurements showed indications of a degradation of the fibre performance.

In conclusion, we consider the hot bump shrinking method as safe.

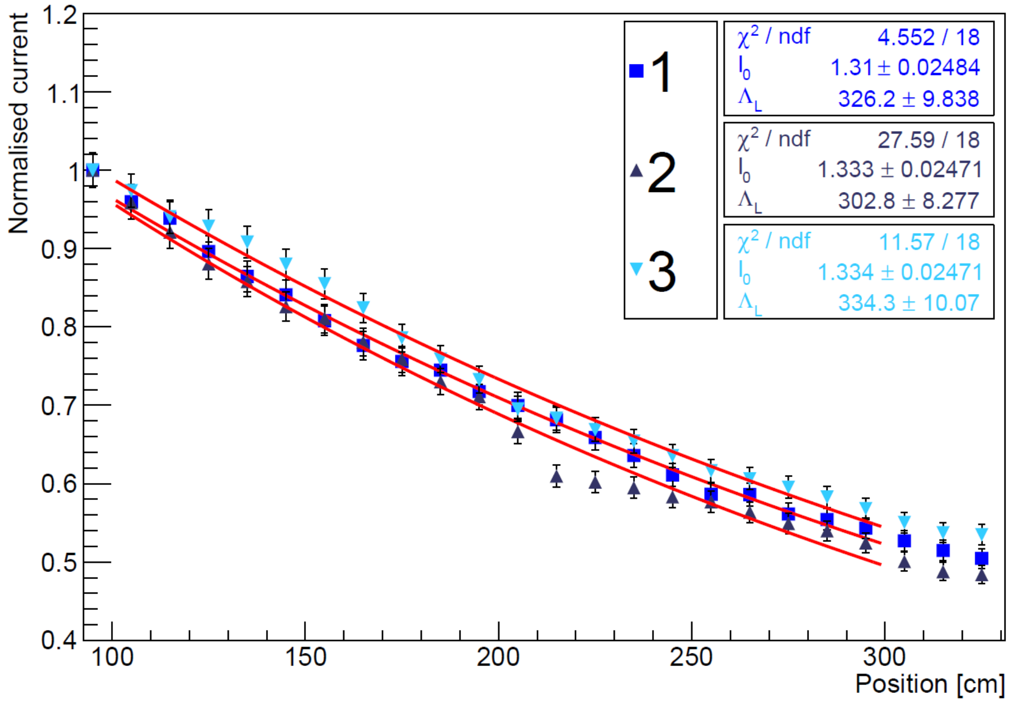
References

[1] C. Alfieri et al., A set-up to measure the optical attenuation length of scintillating fibres, LHCb-PUB-2015-011

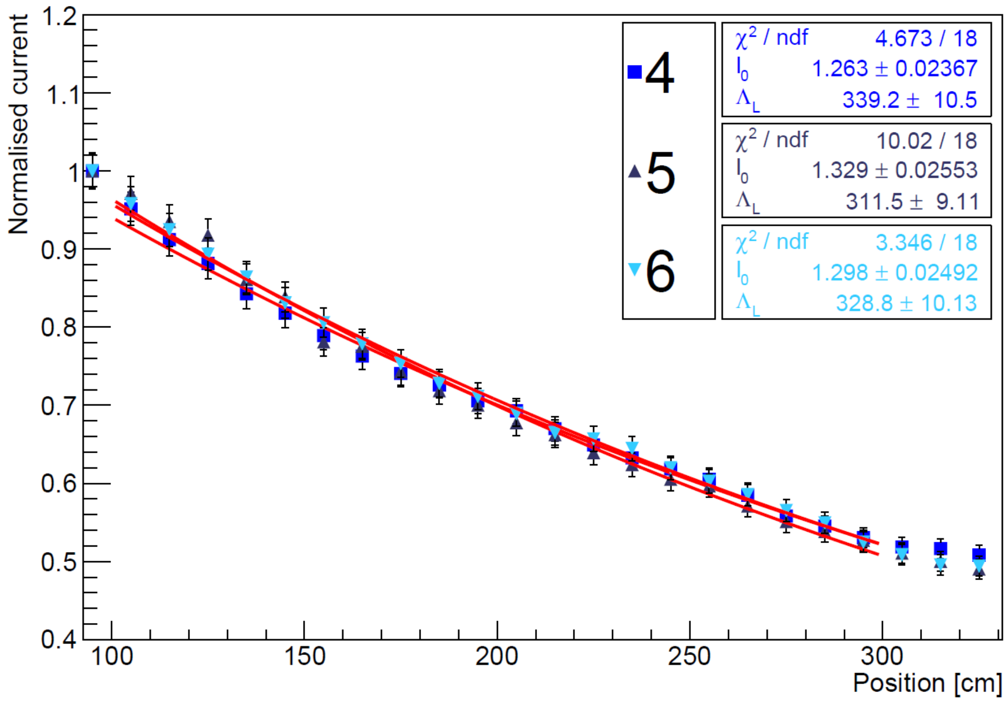
[2] C. Alfieri et al., An experimental set-up to measure Light Yield of Scintillating Fibres, LHCb-PUB-2015-012

[3] A.B. Rodrigues et al., Scanners for the quality control of scintillating plastic fibres, LHCb-PUB-2015-009

A Appendix



Normalised current
Position [cm]
1
2
3
χ2 / ndf 4.552 / 18
I0 1.31 ± 0.02484
ΛL 326.2 ± 9.838
χ2 / ndf 27.59 / 18
I0 1.333 ± 0.02471
ΛL 302.8 ± 8.277
χ2 / ndf 11.57 / 18
I0 1.334 ± 0.02471
ΛL 334.3 ± 10.07



Normalised current
Position [cm]
4
5
6
χ2 / ndf 4.673 / 18
I0 1.263 ± 0.02367
ΛL 339.2 ± 10.5
χ2 / ndf 10.02 / 18
I0 1.329 ± 0.02553
ΛL 311.5 ± 9.11
χ2 / ndf 3.346 / 18
I0 1.298 ± 0.02492
ΛL 328.8 ± 10.13

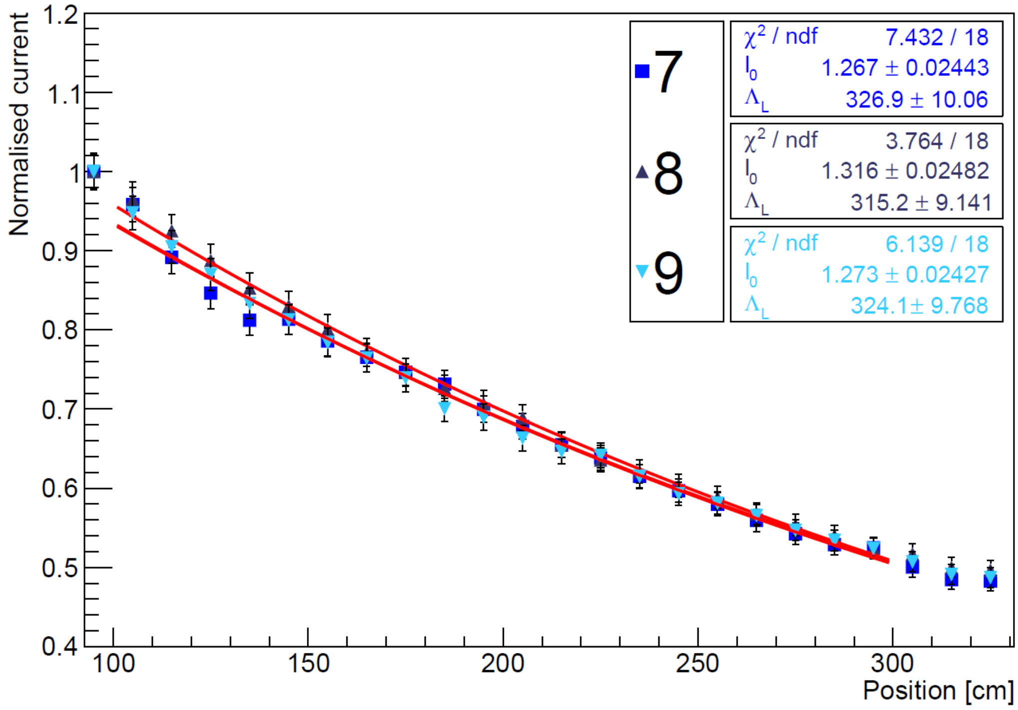


Figure 9: Light attenuation measured for the individual fibre samples. Sample 1-3 were not pulled through the tool. Samples 4-6 were pulled through the hot tool at a speed of 15 cm/s. Samples 7-9 were pulled through the hot tool at a speed of 3 cm/s.