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The WLS Fiber Time Properties Study

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ABSTRACT

The pulse shape properties of different wave-length shifting fibers have been measured. This study intents to help in the right choice of fibers in terms of their further application in the LHCb Hadron Calorimeter as zero-level trigger detector.

The measurements have been done both at the X7 test beamline of the CERN SPS and using ultra-violet N_2 laser as a short light pulse source. Fibers under study have been attached to the standard polystyrene based scintillating tile used in HCAL Prototype. The fast photo-multiplier FEU-115M and digital recording oscilloscope were used.

It was found that the fiber BCF-91A is rather slow ($\tau_d > 10\,ns$) to be accepted for calorimetry in LHCb.

The Fibers Y-11 and Pol.Hi.Tech. are found to be faster ($\tau_d \sim 7\,ns$), and could be used provided their signals are considerably clipped.

The fiber BCF-92 shows best results ($\tau_d \sim 3\,ns$).

The influense of the mirror to the signal shape has been studied.

1 Introduction

The Hadron Calorimeter in LHCb [1, 2] will be used as a zero-level (L0) trigger detector. Therefore it is very important to distinguish interactions with 40 MHz bunch-crossing rate. This imply rather fast optical components to be used in light transmission to photo-detectors. The scintillating tiles based on easy available polystyrene with paraterphenyl(PTP) and POPOP as dopants are known to be fast enough with a typical decay time of a few nanoseconds. The WLS fibers however have wide spread of decay time ranging from 3 to 30 ns.

In this note we describe the results of the comparison of different candidate fibers.

2 The measurement setup

The schematic view of the measurement setup is shown on Fig. 1.

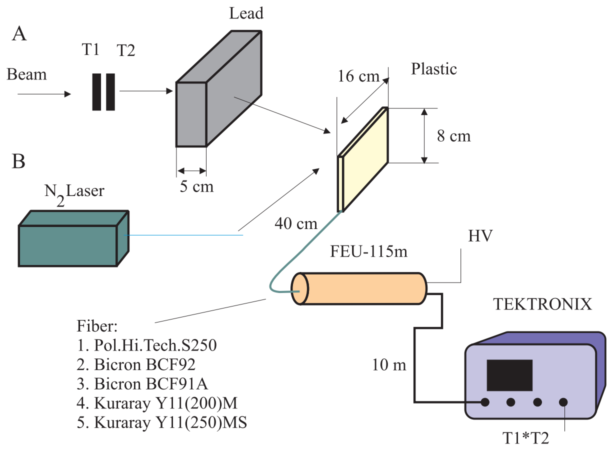

Figure 1: The schematics of the setup to record the WLS fiber pulse shape. The light in the scintillating tile is induced by both, high energy electrons(A) converted in lead and UV-laser pulse(B).

Part of the measurements have been done at the X7 test beam-line of CERN SPS accelerator.A high energy charged particle beam mainly 80 GeV electrons was used.

Those measurements were compared to N_2 UV-laser data. The pulse rate of the laser was about 100 Hz. Special care was taken to reduce noise from the laser. The typical distance between the laser and the PMT was as large as $15 \div 20\,\mathrm{m}$ and the PMT itself has been carefully screened.

The pulse shape was recorded by a fast digital oscilloscope with $5 \div 10$ GHz sampling rate and the data were written on floppy disks.

3 The PMT FEU-115m response to a delta-function like light pulse

All measurements have been performed with fast PMT FEU-115m. The detailed features of this PMT is described elsewhere [3]. For the current study it is essential to know the shape of the PMT response to the shortest available light pulse. To measure it we use the Cerenkov light produced in a 3 cm long cylindrical leucite radiator which was attached to the PMT window via optical grease. This allow to exclude multiple reflections and provide the shortest light pulse from a relativistic charged particle.

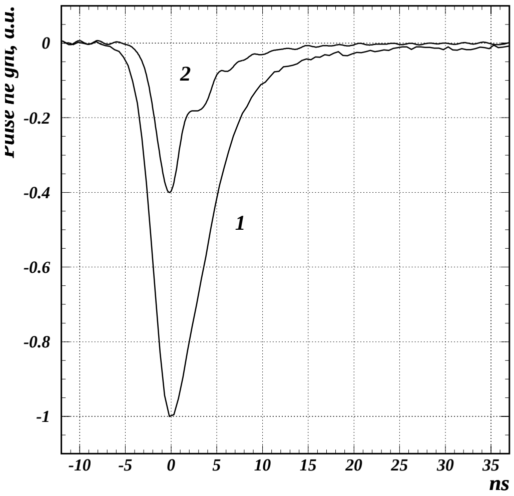

Figure 2: The PMT response to short signal of Cerenkov light(1) and N_2 laser pulse(2). Despite of different pulse-height, the signal rise-time and width coinside within 5 %. Some laser induced noise seen at this early stage of measurement have been excluded later on.

The same measurement has been done with N_2 laser as light source (the pulse is less than 1 ns). In both cases signals have been fed through 10 m coaxial cable and recorded by a digital oscilloscope (see Fig. 2).

The measured signal shapes have been used later in the fit of the fiber signal shapes.

4 The fiber pulse shape measurement results

We use the following fibers from three different manufacturers:

- Pol.Hi.Tech.(S250) fiber used in the HCAL Prototype;
- two types of Y-11 fiber (MS250) and (M200) manufactured by KURARAY;

- three types of BICRON produced fibers BCF-91A (used in HERA-B ECAL), BCF-92 and BCF-99-29A (used in PHENIX shashlik electromagnetic calorimeter at BNL).

Fig. 3 shows the measured pulse shapes.

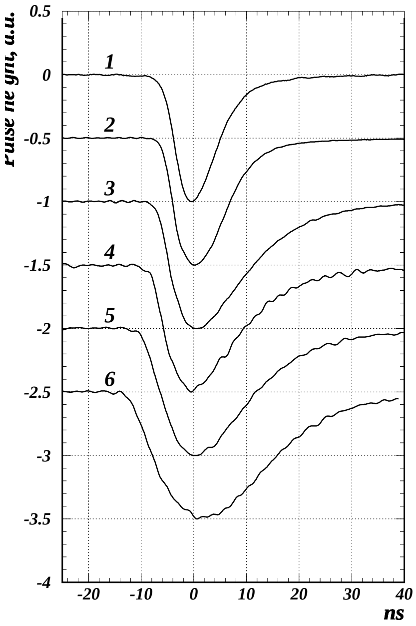

Figure 3: The recorded shapes for different WLS fibers:
1 - BCF-92; 2 - BCF-99-29A; 3 - Pol.Hi.Tech.(S250); 4 - Y-11(MS250);
5 - Y-11(M200); 6 - BCF-91A.

The shortest signal shows the fiber BCF-92 (numbered as 1 in Fig. 3) with 9 ns FWHM. The currently not manufactured BCF-99-26A type is slightly wider (12 ns full width). Two types of fiber have almost equal pulses: Pol.Hi.Tech.(S250) and Y-11(MS250). Those have a width 1.7 times larger than BCF-92. The fiber Y-11(M200) has 18 ns FWHM, e.g. twice as wide as BCF-92. And last one BCF-91A have largest width (23 ns FWHM), in accordance with Technical Data given by BICRON [4].

The first conclusion that could be made is that BCF-91A is too slow to satisfy the requirements for the LHCb experiment. It seems to be impossible to shape it's pulse within 25 ns by means of linear clipping [5] without valuable loss in the pulse height.

We fit the recorded signal shapes by the decay exponentials convoluted with the digitized PMT FEU-115M response to short light pulses. The procedure includes a digital integration according to the following formulae (here we use analytically reduced convolution of two exponentials representing light emission in scintillating tile and reemission in fiber):

$$S(t) = \int\limits_0^t \frac{1}{\lambda_2 - \lambda_1} \left(e^{-\frac{t-\tau}{\lambda_2}} - e^{-\frac{t-\tau}{\lambda_1}} \right) \cdot F(\tau)\, d\tau$$

where

S(t) - the time depending fitting function;

F(t) - PMT FEU-115m apparatus function;

λ_1 - decay time for scintillating tile that have been found to be (1.8 ± 0.3) ns in the separate measurement and used as fixed parameter in this study;

λ_2 - decay time for fiber under study.

The fit includes also the following free parameters: the overall delay (horizontal shift), the pulse-height parameter and the base-line adjust parameter (vertical shift).

The results of this fit shown in Table 1.

Table 1: The fit results of the fiber decay time from pulse shape measurements.

Fiber type	Decay time
BICRON BCF-92	2.4 ± 0.4
BICRON BCF-99-29A	3.5 ± 0.4
Pol.Hi.Tech. (S250)	7.3 ± 1.1
KURARAY Y-11 (MS250)	7.2 ± 1.1
KURARAY Y-11 (M200)	8.8 ± 1.5
BICRON BCF-91A	10.8 ± 2.3

The errors include both fitting and systematic uncertainties. One of the source of systematic error in those measurements are the reflections from the opposite to PMT end of the fiber under study. We use short samples of fibers ($40 \div 60$ cm) and locate tiles near the end of a fiber to minimize this effect. The measured decay time results could be compared to those previousely obtained by the single photo-electron method [6, 7, 8].

5 The light reflection from the mirror on fiber

This section describes how the aluminium mirror on the fiber end distorts the pulse shape. The presence of the mirror increases the fiber light yield and get's better uniformity of responce.

The modified set-up is schematicaly shown in Fig. 4.

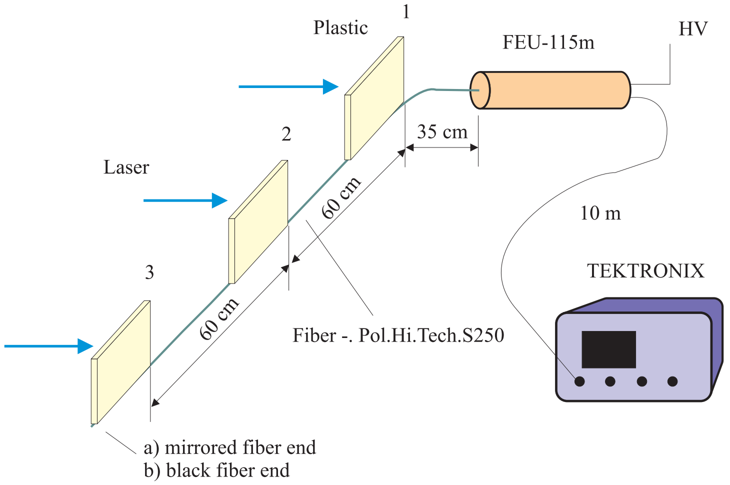

Figure 4: The schematics of the setup to record the WLS fiber pulse shape at different distances from the PMT window. Scintillating tiles with fiber fed through a Tyvek envelope have been moved along the fiber at three different positions. Two measurements have been made: a) with mirror and b) the mirror has been cut and the fiber at the end was painted with black paint.

Two series of pulse shape data have been recorded: with a mirror and with a blackened fiber end. The distance from the tile to the PMT was 35 cm, 95 cm and 155 cm. The fiber of type Pol.Hi.Tech.(S250) was 170 cm long. Fig. 5 presents the pulse shape measurement results.

The effect of light reflection from the mirror is prominently seen. When the tile is close to the mirror there is no increase in the pulse width. Contrary, when the tile is moved to the PMT there are really two light pulses detected by the photocathode: the light emitted directly towards PMT and the light sent to the opposite direction and reflected from the mirror, arriving with a delay equal to the double light pass distance from the tile to the mirrored fiber end. For the blackened end the fiber signal shape remains practically unchanged with the tile position.

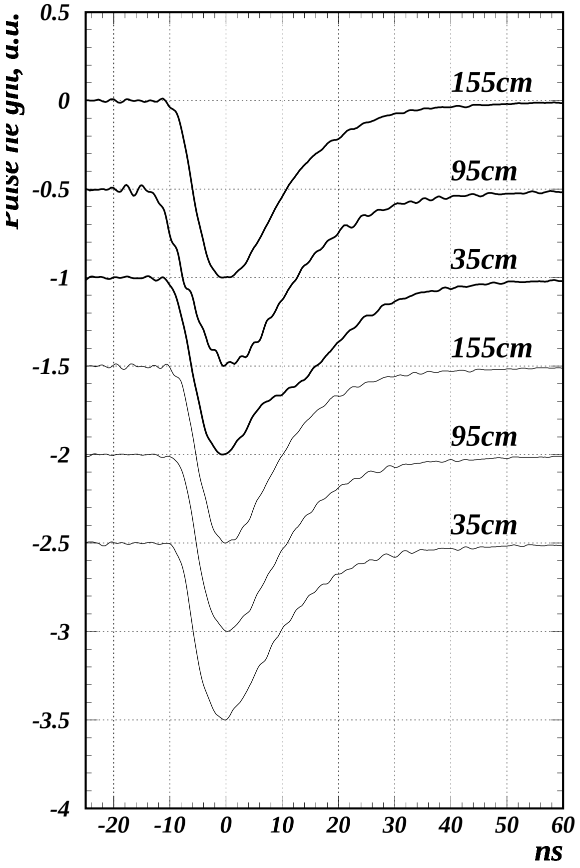

Figure 5: The recorded shapes for different tile distances to PMT. The upper three signal are with mirror, the bottom three with blackened fiber ends. The fiber type is Pol.Hi.Tech (S250) of 170 cm in length. The reflected light pulse clearly seen as a sholder when the tile is 35 cm apart from the PMT.

We apply the same fitting procedure to those signals as described in the previous section, but with adding the reflection term:

$$S_R(t) = S(t) + f \cdot S(t + \Delta t)$$

where

f - is the reflection factor, including attenuation along the fiber;

Δt - delay in light propagation towards the mirror and back, both parameters are free in the fit.

The fit result shown in Fig. 6 corresponds to distance 35 cm. The reflected light path toward mirror and back in this case was equal in average 225 cm. The fit delay parameter corresponds to a light propagation velocity in fiber of (6.6 ± 0.4) ns/m and the mirror reflection factor of 85 %, taking into account the attenuation length in the fiber of 3 m [9] .

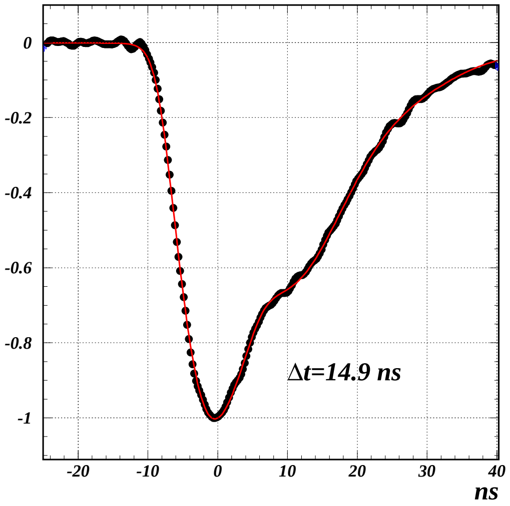

Figure 6: The fit to the recorded pulse shape. The average light propagation distance between the mirror and the tile was 225 cm.

6 Summary

In summary several fiber types have been studied for their possible use in the calorimetry of LHCb. The requirement to those detectors to supply Level-0 trigger data imply strong restrictions on their timing performance, e.g. distinguish events without overlapping in consecutive bunch crossings.

The calorimeter signal pulse length is determined by scintillator and fiber decay time as well as by the photo-multiplier. In Hadron Calorimeter there is an additional timing spread because of shower fluctuation in depth.

Our measurement show that fiber BCF-91A is too slow to be used in LHCb calorimetry. Both Y-11(MS250) and Pol.Hi.Tech.(S250) show an intermediate decay time and could be used when applying a signal clipping to fit in the 25 ns bunch rate [5].

The best timing properties show fiber BCF-92. As a consequence of this study we instrumented part of the HCAL Prototype with those fibers in April'2000 and got excellent signal shapes during 40 MHz bunched SPS beam-test in May. Those results are presented in the note [10].

The mirror at the far end of the fiber essentially increases the light yield for those tiles located at large distances to the PMT. On the other hand the reflection for those tiles in vicinity of the PMT make the pulse-shape wider, but after clipping applyed, this part of the signal has to be cancelled, resulting in improve of the overall uniformity in the calorimeter response.

References

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