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Characterization of new photomultipliers and fibers for the LUCID-3 prototypes for HL-LHC

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Summary. — LUCID-2, the main luminometer of the ATLAS experiment, guaranteed a precision of 1% and a time stability of about 1% during LHC Run-2. Similar performances are expected for Run-3 as well. Due to the higher pile-up and radiation damage, a new LUCID is needed to fulfill the requirements of Run-4. New photomultipliers (PMTs) and fibers have been installed in ATLAS as LUCID-3 prototypes and are evaluated for their use in Run-4. The first results of this characterization campaign are presented. The newly proposed PMTs generate shorter signals compared to LUCID-2 PMTs and the current readout system is not able to digitize them optimally. A fiber irradiation session was performed to estimate the radiation damage during Run-4. A larger loss was observed in the UV region with respect to the visible region, leading to a modification of the fiber prototype installed.

1. – Introduction

Luminosity ($\mathcal{L}$) [1] is a fundamental parameter in any particle collider, since it is related both with the cross section of any process, $\mathcal{L} = \frac{R}{\sigma}$ and with the collider performances, $\mathcal{L}_b = \frac{f_r\, n_1\, n_2}{2\pi\, \Sigma_x\, \Sigma_y}$, where R is the rate of the process and σ is its cross section, $\mathcal{L}_b$ is the luminosity of a colliding proton bunch pair, f_r is the revolution frequency, n_1 and n_2 are the number of protons in the two colliding bunches, while Σ_x and Σ_y are the beams overlap transversal size. Thus, a precise luminosity measurement is crucial for every collider. LUCID-2 [2], the main ATLAS [3] luminometer, is made of 2 symmetric modules $17m$ away from the Interaction Point (IP) along the beam-pipe. Each module is made of 4 groups of 4 PMTs (Hamamatsu R760) and, in Run-2 only, 4 quartz fibers are coupled with PMTs. Radioactive sources of ^{207}Bi are deposited on the PMT windows to monitor their ageing, while, for fiber monitoring, LED light is used. PMT pulses are fed to custom-made VME boards (LUCROD) [2] where signals are amplified, digitized, discriminated and integrated. Different algorithms can be used to measure the luminosity with LUCID (event/hit counting and particle counting), achieving a precision of 1% and a time stability of about 1%. Similar performances are expected also during the Run-3 data taking, but due to higher pile-up and higher radiation damage, LUCID-2 will not be able to operate during the HL-LHC data taking.

2. – LUCID-3

LUCID-3 [4] design aims to achieve the same performances of LUCID-2 during HL-LHC data taking. For testing purposes, LUCID-3 prototypes were installed during shut-down, and will be tested during the entire Run-3. The main goal of the design of the new prototypes is the reduction of particle flux through the detector. PMT-type prototypes obtain this reduction using new PMTs with a smaller window and by placing them farther from the beam-pipe. The Fiber prototype uses quartz fibers as Cherenkov detectors with the readout PMTs in a low-radiation area. It implements a double monitoring system: ^{207}Bi on the PMT window to monitor PMT gain variations and LEDs to monitor fiber degradation.

3. – Prototypes characterization

LUCID-3 prototypes are using Hamamatsu R1635 in the PMT-type prototype and Hamamatsu R7459 in the Fiber prototype and a radiation hard fiber (UVNSS 600/624/660). All these components must the characterized. The characterization of the PMTs can be divided into two different aspects:

- Evaluation of the best working point for each PMT by measuring the absolute gain and relative gain [5] as a function of the high voltage (HV);
- Evaluation of PMT performances using current read-out electronics, suggesting possible improvements for the LUCID-3 readout system.

For fiber characterization, a gamma irradiation was performed, measuring the light output degradation as a function of dose and wavelength.

3·1. *PMT characterization.* – To measure the gain as a function of the high voltage, a radioactive source of ^{207}Bi is placed in front of the PMT window. Signals are measured using 2 different readout set-ups:

- LUCROD is used to measure the amplitude/charge of the signal generated by the bismuth as a function of the high voltage (eq. (1a)/(1b));
- A picoammeter is used to measure the anode current that should follow eq. (1c).

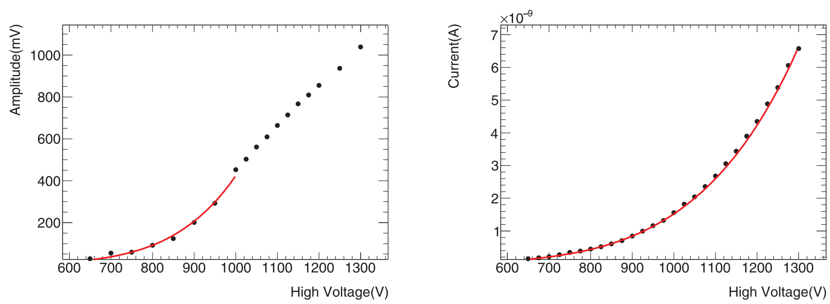
$$A = A_{ref}\left(\frac{HV}{HV_{ref}}\right)^{\alpha}, \tag{1a}$$

$$I = I_{ref}\left(\frac{HV}{HV_{ref}}\right)^{\alpha}, \tag{1b}$$

$$C = C_{ref}\left(\frac{HV}{HV_{ref}}\right)^{\alpha}, \tag{1c}$$

where I, A, C are the current, signal amplitude and charge at voltage HV. HV_{ref}, I_{ref}, A_{ref}, C_{ref} are the same quantities taken at a reference point and α is a parameter that depends on the PMT.

The behaviour of the signal amplitude as a function of HV is shown in fig. 1(a) using LUCROD, while fig. 1(b) shows the current measured by the picoammeter. Measurements for R1635 PMTs are compatible with eq. (1) in the range of $HV < 1000V$ using



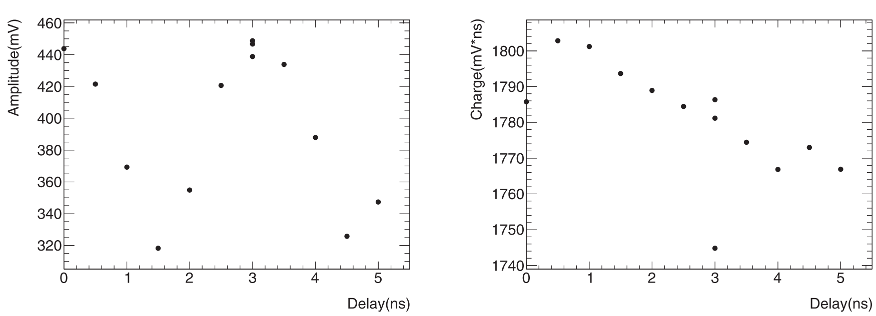
(a) **(b)**

Fig. 1. – R1635 PMT relative gain measured using two different setups. (a) Amplitude measured by the LUCROD as a function of HV. (b) Current measured by a picoammeter. The lines represent the expected behaviour based on eq. (1).

both set-ups, while for $HV > 1000V$ only the current measured with the picoammeter is compatible with expectations. This difference could be due to shorter signals (6 ns) compared with the ones produced by old LUCID-2 PMTs (8 ns) and LUCROD is not able to digitize them properly, since flash-ADC sampling frequency is limited to 320 MHz (3.125 ns). The measurements for R7456 are compatible with eq. (1c) in the whole range. To measure the absolute gain, a LED was operated in single photo-electron regime [5]. The absolute gain of the R1635 at 1000V is $7.9 \cdot 10^5$, while the absolute gain of the R7459 at 1100V is $1.1 \cdot 10^7$.

Variations in the signal arrival time may lead to variations in amplitude and charge measurements. To mimic this effect, the signal arrival time was delayed by spanning two consecutive LUCROD samplings (about 5 ns) by changing the waveform generator delay. Amplitude (charge) showed variation of 28% (5%) (fig. 2). Variations of 10% in amplitude and 5% in charge were obtained with old LUCID-2 PMTs. Different solutions are under study to reduce this effect:

- Increase the readout board sampling rate from 320 MHz to 640 or 1000 MHz;
- Enlarge the PMT signal using pulse widening circuitry;
- Use a charge threshold instead of amplitude for hit definition.



(a) **(b)**

Fig. 2. – Amplitude (left) and charge (right) variation as a function of signal delay. Amplitudes showed a variation of 28%, while the charge showed a variation of 5%.

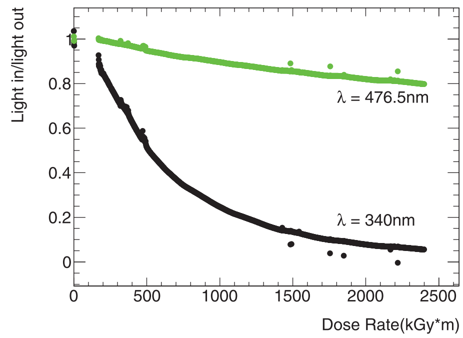


Fig. 3. – Fiber degradation in the UV region (red) and in the visible region (blue) as a function of dose rate.

3˙2. *Fiber characterization.* – A gamma irradiation session was performed at the Calliope Facility at Enea to study the fiber degradation as a function of the light wavelength and absorbed dose. This irradiation session mimics the dose expected in the first three years of HL-LHC data taking. During irradiation, 6 different LEDs ($\lambda = 285$–$627\,\mathrm{nm}$) were cycled. At the end of every LED cycle, environmental light was measured in order to perform offline background subtraction. The transmission loss over 6m of fiber length, rescaled to the length that is expected to be irradiated in LUCID-3 (3.2 m), is shown in fig. 3. A larger loss was observed in the UV (about 95%) region with respect to the visible region($< 20\%$). A UV filter was inserted in one of the prototypes to improve its stability over time by removing the most affected component.

4. – Conclusion

LUCID-2, the main ATLAS luminometer, had good performances during Run-2 and similar performances are expected also during Run-3. Prototypes for a new LUCID that will operate at the HL-LHC were installed and will be studied during Run-3. These prototypes use new PMTs and new fibers. The Hamamatsu R1635 PMT produces a shorter signal compared to the old LUCID PMTs and therefore the current readout board is insufficient to digitize them correctly. Different solutions are currently under study. Fiber degradation under irradiation was studied, showing a larger loss in the UV region with respect to the visible region. A UV filter was inserted in one of the two prototypes in order to improve time stability.

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