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Characterization of avalanche photodiodes (APDs) for the electromagnetic calorimeter in the ALICE experiment

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ABSTRACT

The Electromagnetic Calorimeter (EMCal) of the ALICE experiment at LHC will extensively make use of avalanche photodiodes (APDs) for the readout of scintillation light. The large sensitive area, high quantum efficiency and low dark current make this type of photosensors well-suited for the EMCal requirements. A testing activity is currently in progress in order to characterize the main properties of these APDs and find the best working conditions. Fundamental tasks are the individual test of all APDs after presetting their nominal gain via the bias control and the study of APD gain coefficients as a function of the applied bias voltage and temperature. An overview of the adopted procedure will be presented, together with a description of preliminary results obtained on a first sample of APDs during the testing activity.

1. Introduction

A new Electromagnetic Calorimeter (EMCal) [1] has been recently proposed to be added to the original design of the ALICE detector [2,3] in order to improve the capabilities for jet identification and reconstruction. Combined with ALICE excellent tracking and particle identification, the EMCal will provide a tool for a comprehensive study of "jet quenching" (see e.g. Refs. [4,5]), which represents a powerful probe of the QCD matter at extreme energy densities.

The main features of the EMCal are an efficient and fast low level trigger for high energy jets and the detection of the neutral component of jet energy. The EMCal will also perform, together with the existing PHOS Spectrometer, measurements of high p_t direct photons, neutral mesons and electrons.

The EMCal detector has just entered its construction phase, with the possibility to install one of the 12 planned super-modules inside the L3 magnet even before the start of LHC Pb beams. During the construction activity, one of the required tasks is the test and characterization of the avalanche photodiodes (APDs) which will be used for the readout of the scintillation light. An accurate study of the properties of these photosensors is fundamental in order to achieve a good energy resolution for the electromagnetic showers and provide an efficient high energy shower trigger.

Section 2 describes the main features of the EMCal project, Section 3 contains the description of the experimental set-up and APD testing procedure, Section 4 presents preliminary results from a first lot of devices and finally Section 5 concludes.

2. The EMCal in the ALICE experiment

ALICE is a general-purpose experiment at the CERN Large Hadron Collider, especially conceived for the study of heavy-ion physics. It is designed to track and identify a large multiplicity of particles (dN_{ch}/dy up to 8000) initially predicted in ultra-relativistic Pb–Pb collisions at 5.5 A TeV. Its main task is the study of the high energy density hadronic matter produced in such collisions, which is expected to undergo the transition to the Quark-Gluon Plasma (QGP) phase. A powerful tool to access the properties of this hot and dense medium is the study of jet-quenching. Jet reconstruction based only on charged particles is subjected to severe limitations. The installation of a new electromagnetic calorimeter will improve the jet energy resolution, increase the efficiency for the selection of high-p_t partons

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Fig. 1. Picture of a single prototype module with four towers.

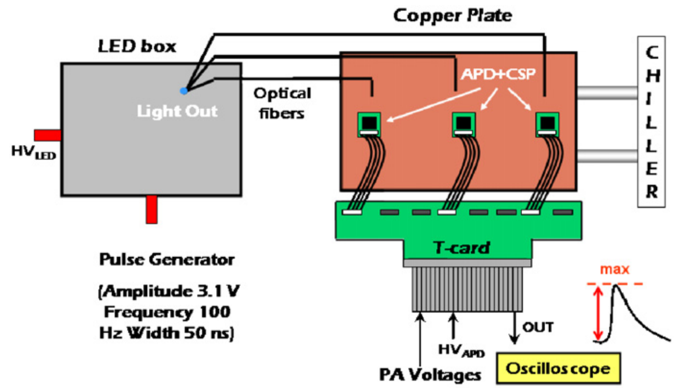

Fig. 2. Sketch of the experimental set-up used for the tests.

and further reduce the bias on the parton fragmentation inherent to leading particle studies.

The proposed EMCal will be located inside the solenoidal magnet of the ALICE detector, in the radial direction between the ALICE spaceframe and the magnet coils. Owing to its position, it will provide partial back-to-back coverage with the photon spectrometer PHOS. It will cover 110° in azimuth and from $\eta = -0.7$ to 0.7 in pseudorapidity, being organized in an array of 12 super-modules, each covering approximately 20° in azimuth at a radial distance of 4.54 m from the IP.

The EMCal detector is based on the Shashlik technology: the smallest building unit of the calorimeter is a tower (Fig. 1), which consists of 77 alternating layers of Pb and polystyrene based scintillator, with front dimensions $6 \times 6\,cm^2$. The whole calorimeter is segmented into 12 672 towers.

Scintillation UV light produced in each tower is collected by an array of 36 fibers, which run longitudinally through the tower and transmit the light to an APD. The selected photosensor is the Hamamatsu S8664-55 (or S8148) APD [6]: it has a large sensitive area of $5 \times 5\,mm^2$, low dark current (typically 3 nA at gain 50) and a very high quantum efficiency, up to 80%. The expected radiation dose at which these APDs will be operated during 10 years ALICE operational scenario is 0.5 Gy, with a neutron (1 MeV-equivalent) fluence in the order of $9 \times 10^{10}\,n/cm^2$ [7]. Such estimates take into account also the effect of beam halo and beam-gas interactions. Radiation hardness studies for such devices have been carried out by Hamamatsu and by the CMS Collaboration, showing excellent performance up to a dose of 5000 Gy and a fluence of $10^{13}\,n/cm^2$ [8].

Since the EMCal detector will work at the ambient temperature in the ALICE environment (+20 °C), the APDs will be operated at a moderate gain of 30 to have low excess noise and high gain stability.

Prior to installation in the EMCal modules, each APD has to be tested with a LED pulser system in order to verify its basic functionality and properties. This testing procedure is the first fundamental step for the EMCal calibration process, since it will allow to equalize the towers response within a resolution of about 5%. In this paper a brief description of the procedure adopted for this testing activity is given and the results obtained from the characterization of a first batch of 170 APDs are shown.

3. Experimental set-up and APD testing procedure

Due to the similarities with the PHOS Spectrometer, the PHOS FEE electronics has been adopted for the EMCal readout, with only minor modifications which concern mainly the dynamic energy-range and shaping time. A detailed description of the whole readout chain can be found in Ref. [9]. However, instead of the standard DAQ chain, a simplified electronics system (Fig. 2) was used to perform the measurements reported here: the APD is directly connected to a Charge Sensitive Preamplifier (CSP) with a sensitivity of 0.833 V/pC, which produces an output voltage step proportional to the charge created in the APD. With an expected light yield of 4.4 photoelectrons/MeV the CSP step signal amplitude covers a linear range of 0.25 mV–4.37 V corresponding to a 14 bit range between 15 and 250 GeV. The step voltage passes through a transition-card (T-card) and is sent to a digital oscilloscope for the measurement and the recording of the CSP signal amplitude.

As light source we used a highly stable blue LED from Kingbright (L7104PCB) [10] with $\lambda = 470\,nm$, triggered by an external pulse generator with a frequency of 100 Hz. Since the gain measurements only require relative signal height measurements, a careful study has been done to ensure a stable LED light intensity over the period of measurement. Optical fibers were used to deliver light pulses from LED to APDs. As designed, the system allows the simultaneous illumination for several APDs.

Since it is well known that APD gain is very sensitive to the temperature, the set-up includes also a system for the control and monitoring of the temperature: the liquid from a chiller flows through a pipe inside a copper plate; the APDs are placed in direct contact with this plate and their temperature is continuously monitored by a thermocouple placed on the APD surface. The use of this system allows a temperature control precision of 0.1 °C.

The main task of these tests is the study of the APD gain dependence on the applied bias voltage and on the temperature: the used experimental set-up provides a good control of both variables and allows accurate measurements in different working conditions. With this system it is possible to reject those APDs which do not fit the EMCal requirements and to predict the behavior of the operating APDs during the ALICE operation.

4. Results

To study the gain dependence on the bias voltage, we systematically increased the reverse voltage till the gain went above the nominal value 30. The shape of the avalanche gain is an exponential function of the applied bias voltage. As an example, Fig. 3 shows the gain curve at the fixed temperature $T = 25\,°C$. After an initial plateau between 20 and 100 V, which defines the unitary gain, the curve exhibits an exponential shape at higher voltages. The curve can be well fitted to an exponential