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Performance of prototypes for the ALICE electromagnetic calorimeter

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ABSTRACT

The performance of prototypes for the ALICE electromagnetic sampling calorimeter has been studied in test beam measurements at FNAL and CERN. A 4×4 array of final design modules showed an energy resolution of about $11\%/\sqrt{E(\mathrm{GeV})}\oplus1.7\%$ with a uniformity of the response to electrons of 1% and a

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good linearity in the energy range from 10 to 100 GeV. The electromagnetic shower position resolution was found to be described by $1.5\,\text{mm} \oplus 5.3\,\text{mm}/\sqrt{E(\text{GeV})}$. For an electron identification efficiency of 90% a hadron rejection factor of >600 was obtained.

1. Introduction

ALICE (A Large Ion Collider Experiment) at the LHC is designed to carry out comprehensive measurements of high energy nucleus–nucleus collisions, in order to study QCD matter under extreme conditions and to explore the phase transition between confined matter and the Quark-Gluon Plasma (QGP) [1,2].

ALICE contains a wide array of detector systems for measuring hadrons, leptons and photons. The ALICE detector is described in detail in Ref. [3]. The large acceptance Electromagnetic Calorimeter (EMCal), which is foreseen to be fully installed in 2011, significantly enhances ALICE's capabilities for jet measurements. The ALICE EMCal is designed to provide the following functions:

- efficient and unbiased fast level L0 and L1 trigger on high energy jets;
- measurement of the neutral portion of jet energy;
- improvement of jet energy resolution;
- measurement of high momentum photons, π^0 and electrons;
- γ/π^0 discrimination up to 30 GeV [3];
- e/h separation (for momenta larger than 10 GeV/c);
- high uniformity of response for isolated electromagnetic clusters.

From Monte Carlo simulations, a detector energy resolution of the order of about $15\%/\sqrt{E(\text{GeV})} \oplus 2\%$ was found to be sufficient for the jet physics program and is fixed as the minimum detector requirement. The electron and photon physics programs, however, would benefit from better resolution.

The overall design of the EMCal is heavily influenced by its integration within the ALICE [3] setup which constrains the detector acceptance to a region of about 110° in azimuth ϕ, $-0.7 < \eta < 0.7$ in pseudo-rapidity and $4.35\,\text{m} < R_{\text{EMCal}} < 4.7\,\text{m}$ radial distance.

This paper presents the performance of prototype modules studied in test beam measurements at FNAL and at CERN. The goals of these measurements were the determination of the intrinsic energy and position resolution, the investigation of the linearity and uniformity of the detector response, the determination of the light yield per unit of energy deposit and a study of the response to electrons and hadrons. Furthermore, monitoring and calibration tools were successfully implemented and tested.

2. Calorimeter module design and readout

The chosen technology is a layered Lead(Pb)-Scintillator(Scint) sampling calorimeter with wavelength shifting (WLS) fibers that run longitudinally through the Pb/Scint stack providing light collection (Shashlik) [4]. The basic building block is a module consisting of 2×2 optically isolated towers which are read out individually; each spans $\Delta\eta \times \Delta\phi = 0.014 \times 0.014$ each. White, acid free, bond paper serves as a diffuse reflector on the scintillator surfaces and provides friction between layers. The scintillator edges are treated with TiO_2 loaded reflector to improve the transverse optical uniformity within a single tower and to provide tower to tower optical isolation better than 99%.

The energy resolution for a sampling electromagnetic calorimeter varies with the sampling frequency approximately as $\sqrt{d_{\text{Sc}}/f_{\text{s}}}$, where d_{Sc} is the scintillator thickness in mm and f_{s} is the sampling fraction for minimum ionizing particles (MIPs). For optimum resolution in a given physical space and total radiation length, there is thus a desire to have the highest possible sampling frequency. Practical considerations, including the cost of the total assembly labor, suggest reducing the total number of Pb/Scint layers thus decreasing the sampling frequency. The requirement of a compact detector consistent with the EMCal integration volume and the chosen detector thickness of about 20 radiation lengths, results in a lead to scintillator ratio by volume of about 1:1.22 corresponding to a sampling geometry of Pb(1.44 mm)/Scint(1.76 mm).

The physical characteristics of the EMCal modules are summarized in Table 1.

Scintillation photons produced in each tower are captured by an array of 36 Kuraray Y-11 (200 M), double clad, wavelength shifting (WLS) fibers. Each fiber within a given tower terminates in an aluminized mirror at the front face of the module and is integrated into a polished, circular group of 36 fibers at the photo sensor end at the back of the module. The 6.8 mm diameter fiber bundle from a given tower connects to the Avalanche Photodiode (APD) through a short light guide/diffuser. The selected photo sensor is the Hamamatsu S8664-55 avalanche photodiode chosen for operation in the high field inside the ALICE magnet. The APDs are operated at moderate gain for low noise and high gain stability in order to maximize energy and timing resolution. The number of primary electrons generated in the APD by an electromagnetic shower is ≈ 4.4 electrons/MeV. The reverse bias voltage of the APDs are individually controlled to provide an electron multiplication factor (M) of 30 resulting in a charge output of ≈ 132 electrons/MeV from the APDs. All APDs used for the test beam measurements were previously calibrated [5]. The charge output from the APD is integrated by a Charge Sensitive Preamplifier (CSP) with a short rise time of ≈ 10 ns and a long decay time of $\approx 130\,\mu$s, i.e., approximately a step pulse. The amplitude of the step pulse is proportional to the number of integrated electrons from the APD and therefore proportional to

Table 1
EMCal module physical parameters.

Parameter	Value
Tower size (at $\eta = 0$)	$\sim 6.0 \times \sim 6.0 \times 24.6\,\text{cm}^3$
Tower size	$\Delta\phi \times \Delta\eta = 0.0143 \times 0.0143$
Sampling ratio	1.44 mm Pb/1.76 mm Scint.
Layers	77
Scintillator	Polystyrene (BASF143E + 1.5%pTP + 0.04%POPOP)
Absorber	Natural lead
Effective RL X_0	12.3 mm
Effective MR R_M	3.20 cm
Effective Density	5.68 g/cm^3
Sampling Fraction	1/10.5
Radiation Length	20.1

Here, RL stands for Radiation Length and MR for the Moliere Radius.

[3] Considering invariant mass and shower shape techniques only.