An electromagnetic calorimeter prototype for the ALICE experiment

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Abstract: The Zero Degrees Calorimeters (ZDC) of the ALICE experiment will be used to measure centrality in heavy ion collisions at LHC. The ZDC setup includes an electromagnetic calorimeter that will measure participants energy. This calorimeter is made of lead with quartz fibres as active material. Cerenkov light produced in fibres by showering particles is carried to a photodetector by means of an air light guide. Because of the relatively low light yield in quartz fibre calorimeters, the optimization of the parameters of the light guide is a crucial point, and it has been carefully studied with Monte Carlo simulations and laboratory tests. A prototype has been tested at the CERN SPS with positron beams at various incident energies. Results on the study of transmission efficiency of light guides and on beam test results on detector performances are presented.

1. Introduction

ALICE (A Large Ion Collider Experiment) [1] will be the dedicated heavy-ion experiment at the CERN LHC collider. It will study strongly interacting matter at high energy densities and in particular the predicted transition from ordinary hadronic to deconfined partonic matter. The ZDC (Zero Degrees Calorimeters) for the ALICE experiment will measure the impact parameter of the collision by detecting the energy carried forward by non interacting (spectator) nucleons. This measure is directly connected with the geometry of the collision since it provides an estimate of the number of participating nucleons.

In nucleus-nucleus collisions fragments formed by spectator protons and neutrons are produced. Unfortunately they will remain in beam pipes since their charge to mass ratio

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is very similar to the ion beam one and they could therefore not be detected by the ZDC. Fragmentation of colliding nuclei affects the correlation between zero degree energy and centrality. In particular for peripheral events energy measured by ZDC is strongly lowered; therefore for a fixed E_{ZDC} value there are two possible impact parameters, one corresponding to central and one to peripheral events. To avoid this ambiguity an electromagnetic zero degree calorimeter is foreseen in the ZDC project. The Zero degrees ElectroMagnetic calorimeter (ZEM) will measure, event-by-event, the energy emitted by participants in the forward direction; therefore it will detect essentially photons generated from π^0 decays. The measured energy is a monotonic function of the impact parameter and therefore it can be used to distinguish central from peripheral collisions, improving thus the centrality trigger.

2. The electromagnetic calorimeter

The detection technique adopted for the electromagnetic ZDC is the quartz fibres calorimetry [2]. The shower generated by incident particles in a dense absorber (the so called "passive" material) produces Cerenkov radiation in quartz fibres ("active" material) interspersed in the absorber. Quartz fibres for this calorimeter are sandwiched in layers between absorber lead plates 3 mm thick and they are tilted at 45° relative to incoming particles in order to maximize the detector response [3]. The active to passive volume ratio is about 1/8. Calorimeter dimensions are of $(7\times7\times21)$ cm^3 for a total absorber length corresponding to about 30 radiation length.

3. Air light guide

R&D studies performed on prototypes with fibres tilted at 45°, showed an increase of the response as a function of the vertical impact point over the detector front face. The strong observed increase in light output was due to the way fibres were coupled with photodetectors: they exited from the absorber plates and were carried to the photodetectors leaving a relatively long section in air. Particles hitting the calorimeter near its edge lead to a very high light yield due to shower particles that transverse fibres in air. The ALICE ZEM has been projected in order to avoid this effect: fibres are cut of the length of lead plates and light produced is optically guided to the photomultiplier by means of an air light guide. Guide geometry and characteristics have been studied in detail in order to optimize efficiency in light transmission and response uniformity as a function of the light production point. The guide has a trapezoidal shape: its bottom face is rectangular with the same dimensions of the calorimeter $(22\times7$ cm$^2)$ and the top one is square (2.8×2.8) cm^2 to fit the cross section of the XP2020 photomultiplier used. A lateral section of the designed guide is shown in fig. 1.

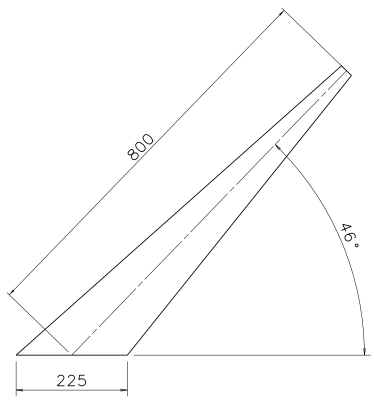

Figure 1: Air light guide lateral section (dimensions in mm).

Guide inclination angle, length and treatment of the inner walls have been simulated to analyze their effect on guide transmission efficiency and uniformity. Inclination angles from 20° to 50° with respect to horizontal plane and guide lengths between 20 and 90 cm were investigated. The best signal uniformity as a function of the light production point was found for a guide tilted at 46° and 80 cm long. A prototype of air guide light with these characteristics was built; inner reflecting walls were obtained with an aluminum layer deposited under vacuum.

The guide was firstly tested in laboratory with a stable light source. Two quartz fibres were lightened by the source, the first one was directly connected to a photomultiplier used as reference, while signal from the second fibre, tilted at 45°, was transmitted through the light guide and collected by a second photodetector. Fibre position under the guide could be varied to study guide transmission efficiency dependence on the light production point. The laboratory test has also allowed a measure of the absolute transmission efficiency by comparing signals obtained with the guide and without it, with the fibre directly connected to the photodetector. It came out that the guide transmitted 31% of the generated photons. The guide was finally tested on positron beams at the CERN SPS accelerator. The experimental setup used was conceptually similar to the laboratory one: four fibres put between two lead slices were moved under the guide and the light output of the photomultiplier was studied for different fibres positions. Results of simulations, laboratory and beam tests on guide uniformity as a function of photon generation point in the longitudinal direction are resumed in fig. 2.

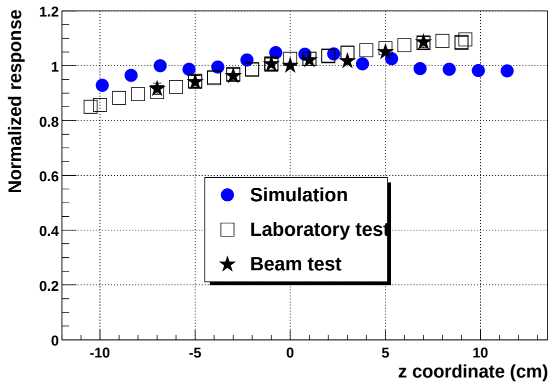

Figure 2: Simulations, laboratory and beam test results for light guide uniformity.

It can be seen that laboratory and beam test results are in a very good agreement. On the contrary, a difference in signal behavior between simulations and experimental results can be noticed. For this reason further test were performed in laboratory to study different inclination angles. Guides tilted from 46° to 52° were tested; in fig. 3 results for the most significative angles are plotted. The pattern found in simulations is reproduced by higher inclination angles and the guide that has shown the best signal uniformity is the one tilted at 51°.

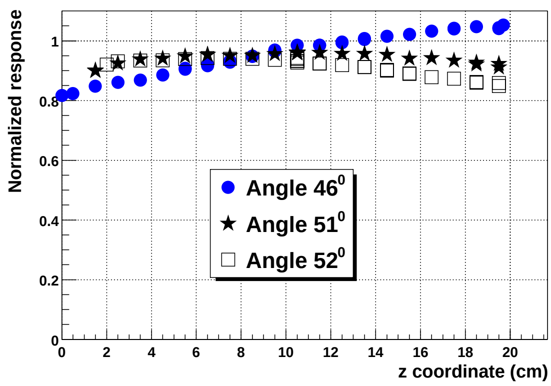

Figure 3: Results on transmission efficiency for different guide inclination angles.

Guides with shorter lengths have also been tested: their transmission efficiency is comparable to the one measured for longer guides, but they showed a less uniform output as a function of light production point that can be inputed to the lower number of photon reflections inside the guide. Finally we also tested a guide with diffusing inner walls (painted in white), but its transmission efficiency was 1/5 with respect to the reflecting one.

In conclusion the air light guide that has shown the best performances and that will therefore be used for the ALICE electromagnetic calorimeter will be the one 80 cm long and tilted at 51° with reflecting inner walls.

4. Beam test results

In 1999 a prototype of the ALICE electromagnetic zero degree calorimeter equipped with its air light guide was tested with positron beams at the CERN SPS. Aim of the test was to study detector response and energy resolution as a function of the incident energy. Also detector response as a function of particle impact point over its front face was studied and it was found that the air guide light completely solve the problem of the increasing signal observed with fibres directly connected to the photodetector.

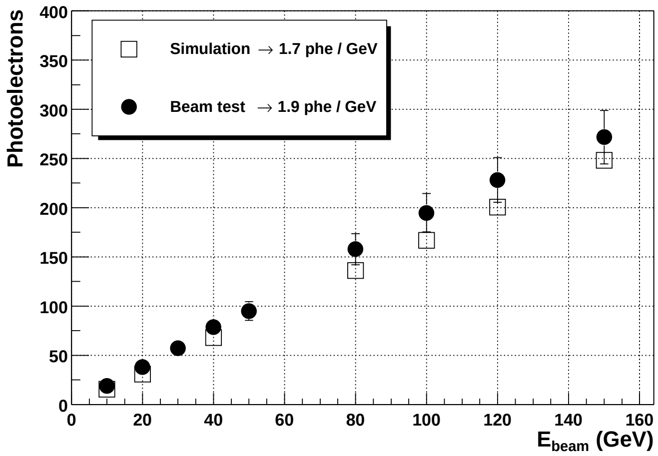

Figure 4: Response of the calorimeter as a function of incident energy.

In fig. 4 and 5 beam test results are shown and compared to simulations performed with GEANT 3.21 [4]. Detector response as a function of beam energy gives a light yield of 1.7 photoelectrons per GeV and the result found in simulation is quite similar. The energy resolution is usually fitted with the quadratic sum of two independent terms: $\sigma/\mathrm{E} = \mathrm{a}/\sqrt{E} \oplus \mathrm{b}$, the first one due to statistical fluctuations and the second to instrumental factors (such as calibration errors). For the tested prototype the fit of resolution as a function of incident energy gives only a statistical term different from zero, with $\sigma/\mathrm{E} = 0.69/\sqrt{E[GeV]}$ in beam test and $\sigma/\mathrm{E} = 0.74/\sqrt{E[GeV]}$ in simulations. A better resolution is found in simulations where the light yield is slightly lower, indicating that experimental light distributions have larger widths.

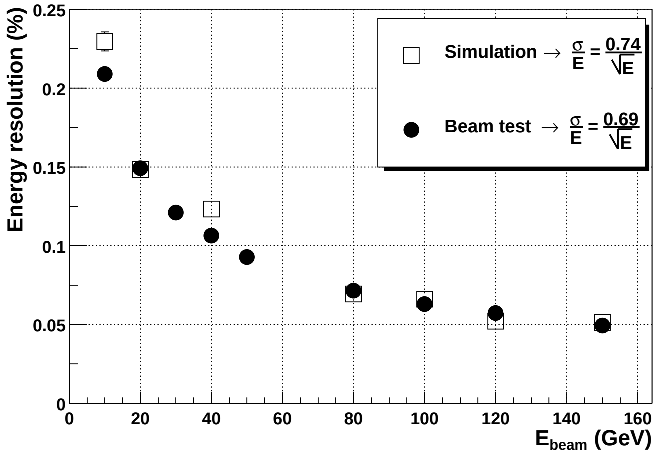

Figure 5: Energy resolution of the detector as a function of incident energy.

5. Conclusions

An electromagnetic calorimeter is included in ALICE ZDC setup to improve the centrality trigger. It will be equipped with an air light guide to assure a uniform response as a function of particle impact point over its front face. Characteristic of the light guide have been chosen on the basis of simulations and experimental tests. It has emerged that reflecting inner walls, a length of 80 cm and an inclination angle equal to 51° are the parameters that optimize both the response uniformity as a function of the light production point and the transmission efficiency of the light guide.

A prototype of the calorimeter with the air light guide has been tested on particle beams. It has shown a good linearity as a function of incident energy with a light yield of 1.9 photoelectrons per GeV. The energy resolution extrapolated to ALICE energies will be $< 1\%$ for central collisions and equal to 1.8% in central ones. This results assure that the designed detector with the air light guide can be successfully adopted at ALICE for participants photons energy measurement.

References

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