THE ALICE ZERO DEGREE CALORIMETERS

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In the Alice heavy-ion experiment at LHC a set of Zero Degree Calorimeters (ZDC) has been proposed to determine the centrality of the nucleus-nucleus collisions, measuring the energy carried away by the non-interacting nucleons. A series of prototypes have been built and tested; the preliminary results concerning the linearity, the resolution, the uniformity of the response as a function of the beam impact point are shown

1 Introduction

The ALICE experiment [1] is dedicated to the study of ultrarelativistic heavy ion collisions where nuclear matter at high temperatures and energy densities can be produced. ALICE is planned to start taking data in 2005, at the LHC facility at CERN, with two colliding lead ion beams at a c.m. energy of $\sqrt{s} = 5.5$ TeV per nucleon.
In heavy-ion collisions, the event by event determination of the centrality plays a basic role; it is used at the trigger level to enhance the sample of central collisions, and, more generally, to estimate the energy density reached in the interaction. The energy E_S carried away by the non-interacting nucleons (spectators)is the measurable quantity most directly related with the centrality of the collision.

2 The ZDCs at the LHC collider

At an ion collider experiment, like ALICE, the design of devices for the detection of spectator nucleons differs significantly with respect to a fixed target one. As can be seen in Fig. 1, where a conceptual sketch of the LHC beam line close to the ALICE intersection point (IP) is presented, the colliding beams are deflected by means of the separation dipole D1 at about 50 m from the IP in order to reach the nominal distance (188 mm for the LHC [2]) between the circulating beams. The D1 magnet will also deflect the spectator protons, separating them from the spectator neutrons, which fly away at zero degrees. It is therefore conceptually possible to place in front of the dipole D2, at ∼ 115 m from the intersection point, on the two sides of the IP, a set of two calorimeters : one of them, positioned between the two beam pipes, to intercept the spectator neutrons, and the other one, external to the outgoing beam, to collect the spectator protons [5].

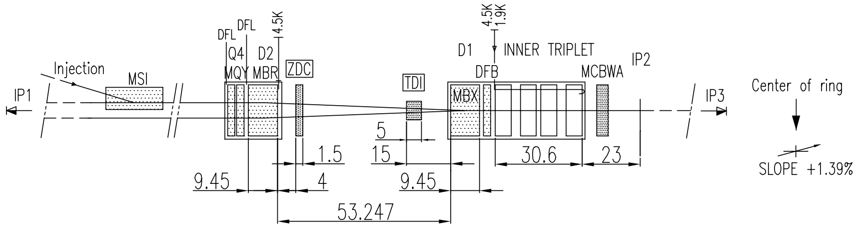

Figure 1. Line sketch from the intersection point IP2 to D2 magnet.

The transverse available space between the outgoing and incoming beam pipes, where the neutron calorimeter (ZN) should be placed, is less than 9 cm. However, the size of the spectator neutron spot on the front face of the neutron calorimeter, essentially due to the Fermi momentum distribution, is quite small ($0.6 \times 0.6\ cm^2$ at 1 σ level), and we expect no losses of neutrons along the beam line. On the contrary the spatial distribution of the spectator protons on a plane normal to the LHC beams axis, located at 115 m from the intersection point, has been found to depend strongly on both the Fermi momentum of the nucleons and on the parameters of the LHC optics. The acceptance of the proton calorimeter (ZP) closely depends on the aperture of the separation magnet D1. Assuming an inner diameter of 73 mm for the beam pipe inside the coils of D1, a Monte Carlo simulation shows that 13% of the protons interact with the beam pipe at the exit of D1 before reaching the ZDCs.

3 Detection technique

The design of ZDCs in the LHC environment has to satisfy various technical issues. As we have seen, the horizontal transverse dimension of the neutron device in any case must not exceed the distance between the two beam pipes in that region ($\sim$ 8 cm), meaning that an extremely compact detector is needed. Furthermore, the ZDCs, even if they do not intercept the beams as at fixed target experiments, will operate at a high radiation level; the deposited dose in the neutron calorimeter is estimated to be $\sim$ 1 Mrad/day, at a LHC luminosity $\mathcal{L}$=10^{27} cm^{-2}s^{-1}.

Because of these constraints, we choose as detection technique for the ALICE ZDCs the quartz fibre calorimetry, which allows to build compact and radiation hard devices. After an exploratory R&D phase [3], quartz fibre calorimetry has been successfully used for the ZDC of the NA50 experiment [4], where a device made of quartz fibres embedded in a tantalum matrix, of dimensions $5\times5\times65$ cm^3, has worked in an environment 10 times more compelling than the ALICE one in terms of radiation levels.

In addition, quartz fibre calorimeters are intrinsically insensitive to radioactivation background, which produces particles below the Cherenkov threshold; moreover, their response is very fast, the signal duration being almost completely dominated by the readout electronics and the cables.

Small dimensions ($8 \times 8 \times 100$ cm^3) and the use of a dense material, like tantalum, are required for the neutron calorimeter (ZN). The transverse dimensions of the proton calorimeter (ZP) should be chosen in order to ensure that most of the spectator protons are collected; the relative big dimensions (of the order of tens of cm) suggest the choice of brass as a matrix material. The fibre-to-absorber filling ratio has to be chosen as a good compromise between the required energy resolution and the fibre cost, after simulations and experimental tests.

4 The NA50 calorimeter as the ALICE ZN prototype

The ZDC calorimeter, now in use in the NA50 experiment, can be considered as the ALICE neutron calorimeter prototype. In fact, the NA50 calorimeter has tantalum as the absorber material and has similar dimensions ($5 \times 5 \times 65$ cm^3); the active part of the detector is made of 900 quartz fibres with silica fluorinated cladding, uniformly distributed with a pitch of 1.5 mm corresponding to a quartz to tantalum volume ratio of 1/17. The fibres are oriented at 0° with respect to the beam direction. A complete description of the calorimeter together with the obtained results can be found in Ref. 4.

A light yield of about 0.5 photoelectron per GeV was observed using a photomultiplier with a bialcaline photocatode and a borosilicate window.

The resolution of the calorimeter for the Pb ion beam of 158 AGeV is 6%, obtained with a gate width of 12 ns.

The ZDC, tested with electron and proton beams, resulted highly non compensated giving an e/p ratio of 2.4. However, this fact does not give any problem when the calorimeter is used as centrality detector, since it measures the number of residual nucleons after the interaction of a Pb nucleus with the target nuclei. In this case the ZDC detects mainly hadrons, all having the same fixed energy per nucleon as the beam.

5 Proton calorimeter prototypes

Two ZP prototypes (named ZP2 and ZP7) have been constructed with different geometrical and mechanical characteristics, summarized in Table 1. They are both equipped with PMMA fibres. In fact, the use of the more expensive quartz fibres is not necessary for the prototype tests, since the radiation damage will be negligible.

The detector configuration is similar to the NA50 ZDC, with the fibres parallel to the beam axis. The photomultipliers are connected to the fibres in such a way that each PMT collects the light from a subset of fibres uniformly distributed in the passive material (see Fig. 2); in this way, considering one or more PMTs, we obtain different quartz/absorber volume ratio. The ZP7 calorimeter is equipped with 2 Philips XP2020 PMTs, while the Cerenkov light from the ZP2 is read by 4 XP2020 PMTs. The two calorimeters have approximately the same filling ratio (1/80).

Table 1. Proton ZDC prototype parameters.

	ZP2	ZP7
Absorber	copper	brass
Number of plates	40	26
Plate thickness	4 mm	6 mm
Fibres material	PMMA	PMMA
Fibre diameter (μm)	500	750
Total number of fibres	1600	676
Fibre pitch	4 mm	6 mm
PM used	4	2

The performances of the two prototypes were studied at the H6 test beam of the CERN SPS with hadron beams of 50, 100, 120, 150 and 180 GeV/c, and with positron beams of 50, 75, 100, 120 and 150 GeV/c.

The experimental setup, shown in Fig. 3, consists of a plastic scintillator hodoscope, used as trigger system, two small and movable scintillator-sticks used to localize the beam position on the calorimeter surface with an accuracy

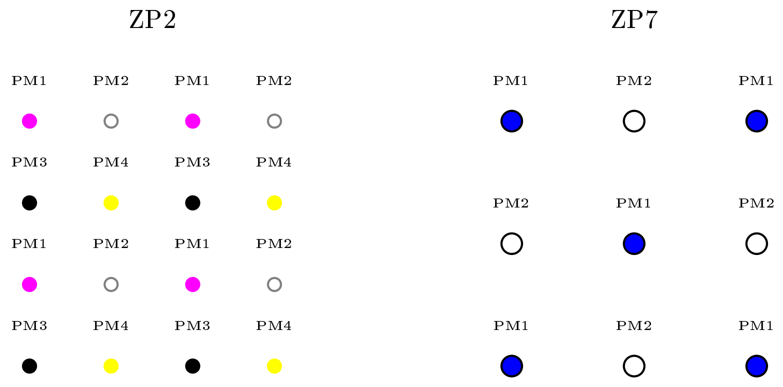

Figure 2. The connection of the fibres to the photomultipliers for ZP2 and ZP7.

of 1 mm in x and y direction, a MWPC with delay line readout, allowing a spatial resolution of 200 μm, installed in front of the calorimeter. The calorimeter itself is placed on a movable platform; a couple of plastic scintillation counters beyond an iron wall detects muons.

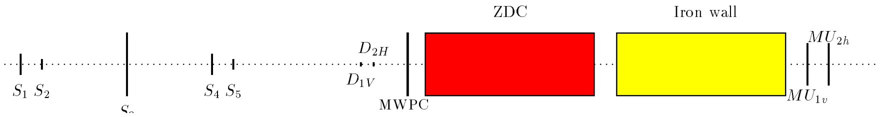

Figure 3. Experimental setup of the test. S_1, S_2, S_3, S_4, S_5: trigger scintillators. D_{1V}, D_{2H}: scintillator sticks. MU_{1v}, MU_{2h}: scintillators for muon detection.

For both prototypes we measured the linearity of the detector response as a function of the energy, the energy resolution for different fibre to absorber filling ratios and for different fibre spacings, the shower transverse size and the uniformity of the response as a function of the beam impact point on the front face of the calorimeter.

The fibres connected to each PMT were uniformly distributed in the passive matrix, so that each channel could detect the same amount of energy. A first equalization of the PMT high voltages was done at the beginning of the test with a hadron beam of 100 GeV/c. A fine tuning of the ADC signals for each channel was made offline to compensate possible small differences.

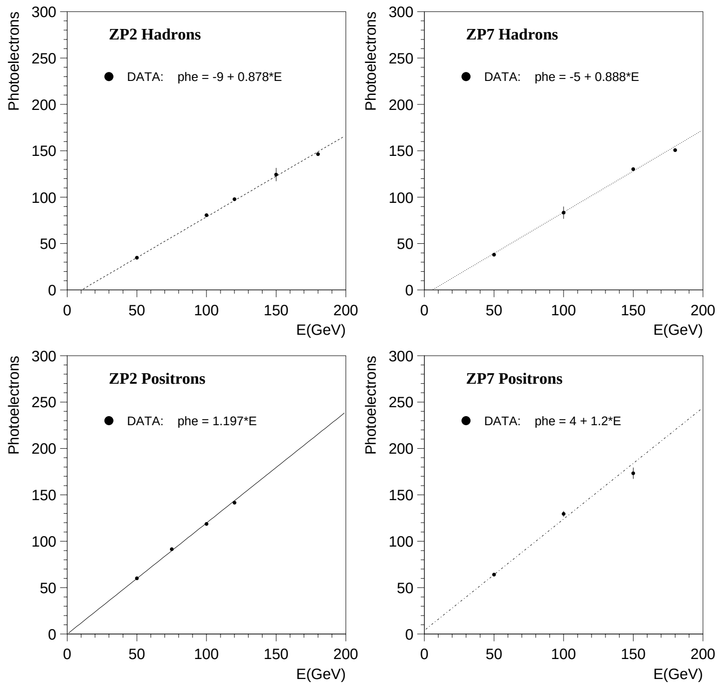

Figure 4. Top: response as a function of the hadron beam energy E for the ZP2 (left) and ZP7 (right) prototypes. Bottom: same for positron beams.

The response as a function of the beam energy (Fig. 4) is expressed in number of photoelectrons; the results show a good linearity. An energy threshold at few GeV can be noticed.

In Fig. 5 the resolution is plotted for different filling ratios, obtained selecting the signals from 1, 2 or 4 PMTs in ZP2 (the filling ratios are respectively 1/325, 1/162, 1/80), and 1 or 2 PMTs in ZP7 (with filling ratios equal to 1/170 and 1/80). The experimental points are fitted with the function $a/\sqrt{E(\mathrm{GeV})}$. The determination of a (small) constant term doesn't appear reliable at these energies. However, we can exclude, with a confidence level of 99%, a value of the constant term greater than 10%.

In order to estimate the hadronic shower transverse size, we studied the response of the calorimeter as a function of the horizontal beam impact co-

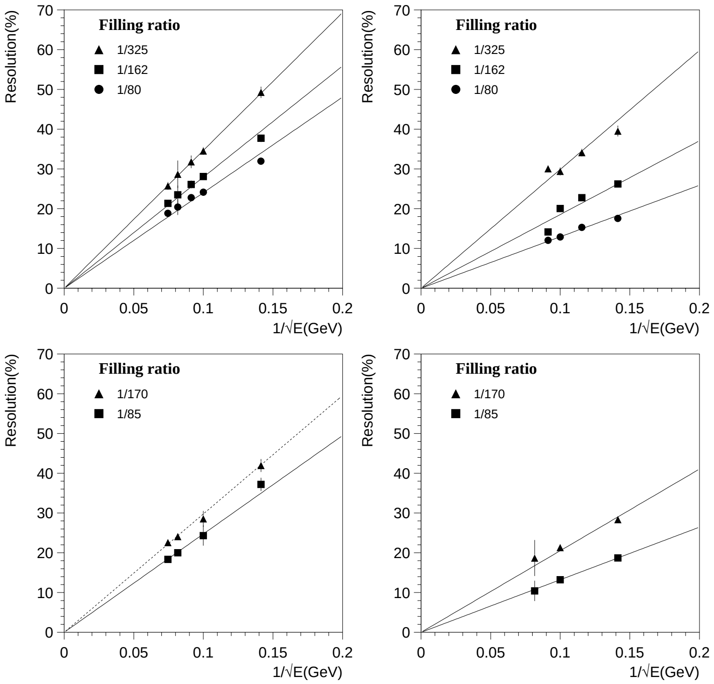

Figure 5. Top: resolution ($\frac{\sigma(E)}{E}$) as a function of $1/\sqrt{E}$ for the ZP2 prototype in hadrons (left) and positrons (right) considering different filling ratios. Bottom: same for ZP7.

ordinate. The information about the beam position is given either by the MWPC or by the 1×1 mm^2 scintillators. Making the derivative of the curve of the response of the ZDC at the edges of the calorimeter, the hadron shower transverse size could be evaluated; we found a value of 2.2 cm (FWHM).

The detector response for hadrons should not be sensitive to the beam impact point with respect to the fibre position. As a result of the test, we found that the response for hadrons can already be considered uniform for a filling ratio of 1/162,when the fibre pitch is 4 mm, as in ZP2, approximately equal to half the radiation length.

6 The proposed ALICE calorimeters

The neutron ZDC will be placed at 116.1 m from the IP. A device, made of quartz fibres embedded in a tantalum matrix, of dimensions $7{\times}7{\times}100$ cm^3, allows to contain 80% of the shower generated by the spectator neutrons. The fibres with a core diameter of 365 μm will be oriented at 0° with respect to the beam axis. The foreseen quartz to absorber volume ratio will be 1/22. The expected resolution for a 2.7 TeV neutron is $\sim$ 10%.

The proton ZDC will be placed at 115.6 m from the IP. To collect most of the spectator protons after the fly path along the magnetic line and to obtain a shower containment and an energy resolution similar to the one of the neutron ZDC, a device of $20.8\times12\times150$ cm^3, centered at 19 cm from the beam axis, made of quartz fibres embedded in a brass matrix, will be used. The fibres will have a core diameter of 550 μm and will be oriented at 0° with respect to the beam axis. The foreseen quartz to brass volume ratio will be 1/65.

Two identical sets of calorimeters will be placed on both sides of the IP to improve the resolution of the impact parameter; moreover, the correlated information will be used to remove the background from beam-gas interactions.

7 Conclusions

We have discussed the characteristics of the proposed ZDCs for the ALICE heavy-ion experiment at the LHC collider. The aim of these calorimeters is the determination of the centrality of the Pb-Pb collision, through the measurement of the energies carried out by the spectator nucleons. The basic requirements of these calorimeters are the radiation hardness and the necessity of having a small shower transverse size. An extremely compact calorimeter, made of tantalum and quartz fibres, is proposed to detect the spectator neutrons, whilst the energy of the spectator protons will be measured by means of a brass-quartz fibre calorimeter. The resolution of both calorimeters is expexted to be of the order of 10% for a 2.7 TeV spectator nucleon, according to simulation. The proposed design for the ALICE ZDCs should ensure an estimation of the impact parameter of the collision within an uncertainty of 10% for all but the most central events.

References

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