Performance of the LHCf detectors

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Abstract. **LHCf is an experiment dedicated to the measurement of neutral particles emitted in the very forward region of LHC collisions. Two independent detectors were designed to measure the particle energy and the incident position with the resolutions of <5% and <200 μm, respectively, for the gamma-rays of >100 GeV. The performance of the detectors was tested at the CERN SPS North Area H4 beam line in August-September 2007. Results of the beam test were well explained by Monte Carlo calculations used in the prediction of the LHCf performance at the LHC energy.**

***Keywords*: high-energy cosmic-ray, hadron interaction model, LHC**

I. INTRODUCTION

The LHC forward experiment (LHCf) is one of the six LHC experiments to perform a measurement of the very forward production cross sections of neutral pions and neutrons. Data taking of LHCf is planed at the very beginning of the LHC commissioning when the luminosity is below $10^{29}\,\mathrm{cm^{-2}s^{-1}}$. With about 10^3 sec of operation, LHCf can provide sufficient statistics to discriminate between the hadron interaction models used in the air shower simulations. To achieve this goal, the energy and position resolutions of <5% and <200 μm, respectively, for the gamma-rays of >100 GeV are required to the detectors. These requirements must be met with compact detectors due to the limited installation space and the high particle multiplicity in the forward region. The LHCf detectors were designed to satisfy these requirements. In this paper, we report the results of the beam test carried out at CERN SPS to confirm the performance of the LHCf detectors. The results were also compared with the Monte Carlo culculations that are used to evaluate the performance up to the LHC energy. Detail of the experiment and detectors are found elsewhere [1] [2] [3] [4] [5] and the other papers presented in this conference [6] [7] [8] [9] [10] [11].

II. THE LHCF DETECTORS

LHCf has two independent detectors named Arm1 and Arm2. Each detector contains two sampling shower calorimeters with four position sensitive layers. The transverse sizes of the calorimeters are 20 mm×20 mm and 40 mm×40 mm for Arm1 and 25 mm×25 mm and 32 mm×32 mm for Arm2. The calorimeters are composed of 22 tungsten plates and 16 plastic scintillators (Eljen Technology EJ-260) with the total thickness of 44 radiation lengths (1.7 hadron interaction lengths). The 3 mm thick scintillators sample the energy deposit every 2 radiation lengths in the first 11 layers and 4 radiation lengths in the deeper layers. The lights from each scintillator are read out by a PMT (HAMAMATSU H7400U) through a bandle of clear fibers

The position sensor of Arm1 is composed of 4 X-Y pairs of SciFi belts (KURARAY SCSF-38) those are inserted at the radiation lengths of 6, 10, 30 and 42. A SciFi belt consists of 20 (40) SciFi's in a single hodoscope plane for the 20 mm (40 mm) calorimeter. Each SciFi has 1mm square cross-section. The total 480 channels of SciFi signal are read out by 8 MAPMTs (HAMAMATSU H7546), each having 64 anodes.

The position sensor of Arm2 is composed of 4 planes of microstrip silicon sensors inserted at the 6, 12, 30 and 42 radiation lengths. Each plane consists of 2 single-sided sensors, identical to those used by the ATLAS experiment [12]. These silicon sensors have

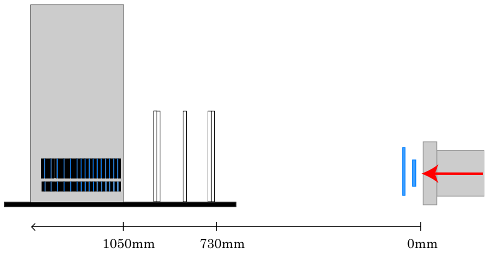

Fig. 1: Setup of the SPS experiment (not in scale). The dark and big rectangles indicate the place of the LHCf calorimeters and their container, respectively. Beam enters from right along the arrow and tagged by two small plastic scintillators. In front of the detector a silicon tracker ADAMO was installed on the movable table together with the LHCf calorimeters.

64 mm × 64 mm total surface area, which is enough to cover the entire cross section of the calorimeter. A sequence of microstrips with 80 μm pitch is implanted on the junction side while the read-out pitch is 160 μm.

III. Beam Test at SPS

The performance of the two detectors was tested at the CERN SPS North Area H4 beamline from 24 August to 11 September 2007. Both detectors were exposed to electron, hadron and muon beams. Electron beams with energies of 50, 100, 150, 180 and 200 GeV, hadron beams with energies of 150 and 350 GeV and a muon beam with an energy of 150 GeV were used. In the following sections, the results obtained from the electron beam are presented. Monte Carlo calculations associated with the experimental results were performed using the EPICS code [13].

The setup of the test is illustrated in Fig.1. One of the detectors was placed on a movable table in the beam area. Data from the calorimeters and position sensors was recorded when triggered by scintillators placed in front of the detector. At the same time, data from an external silicon strip detector (ADAMO) [14] installed between the detector and the trigger scintillators were also recorded. These data are used to precisely determine the incident position of the beam particle for comparison with the internal position sensitive layers.

IV. Energy Resolution

The energy of the incident electron is estimated by summing the deposit in the scintillator layers. In the summation of the deep layers, the deposit energy was doubled because of the half sampling rate in these layers. The conversion factors from the AD counts obtained in the experiment to the energy deposit were determined by comparing the experiment and Monte Carlo calculation of the 150 GeV electron showers for each layer (Fig.2). Due to the small transverse sizes of the calorimeters, a certain fraction of the shower particles leaks out from the calorimeters. Because the fraction is only a function of the incident position and

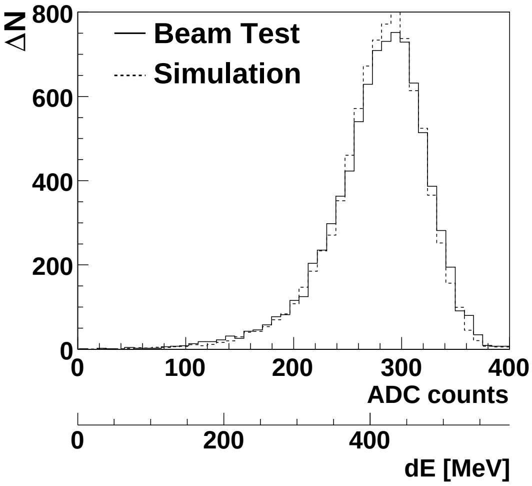

Fig. 2: Comparison of the charge distribution measured by ADC and energy deposit calculated by MC simulation in the 4^{th} layer of the calorimeter for 150 GeV electron showers

independent from the energy, the measured energy is corrected according to the position measured by the position sensors. However, the events fell <2 mm from the edge of the calorimeters were removed because they cause a large scatter even after the leak correction. Detail procedure of the correction was studied for the prototype detector [15], and the main idea described there is used in the correction of the final detectors.

The energy resolution is defined as the r.m.s. of the corrected-summed energy. Because the results of the Arm1 detector were already reported in [2], here the results of the Arm2 25 mm calorimeter is presented in Fig.3. The difference of two series of the resolution designated as '450V' and '600V' are for the different gains of the PMTs used for the calorimter. Because the electrical pedestal fluctuation, that dominates the resolution in the lower energies, is independent from the PMT gain, the data with the higher gain results better resolution. This effect is included in the MC simulation and the results are in a good agreement with experiment as seen in Fig.3. The operation at LHC will be carried out with 450 V to assure a wide dynamic range upto 7 TeV. Because the energy resolution at the 450 V operation is just at the requirement limit (5% at 100 GeV), an operation with a higher gain to cover lower energy with better resolution is planned for the LHC operation. Same conclusion is obtained for all four calorimeters.

V. Energy Linearity

The summed energy deposits are plotted as a function of the incident energy in Fig.4 for the 20 mm and the 40 mm calorimeters in Arm1. The dotted lines show the linear fits of the experimental data (filled marks). The scatter from the fits is <1% for the experimental data

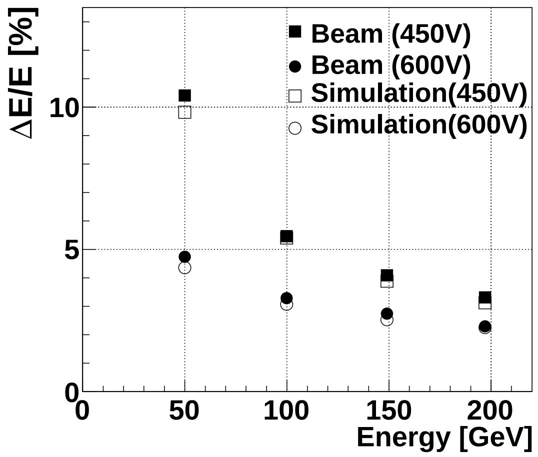

Fig. 3: The energy resolutions of the 25 mm calorimeter as functions of the incident electron energy. Difference in the two PMT gains (450V and 600V) is due to the effect of the pedestal fluctuation measured during the beam test. The results of MC simulation including the pedestal effect are also plotted.

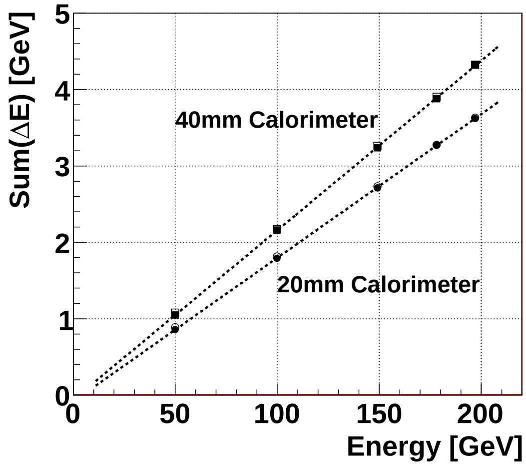

Fig. 4: Linearity of the energy estimator. The summed energy deposits obtained from the experiment (filled marks) and the MC simulation (open marks) are plotted as functions of incident energy. Two series are the results for the 40 mm and the 20 mm calorimeters of the Arm1 detector. Dotted lines are the linear fits of the experimental data.

in all energies. Though the MC result (open marks; overlapped with the experimental data in the figure) deviates 2–3% at the lowest energy, it agrees within 1% over 100 GeV.

The energy estimator is known to be linear up to the LHC energy of 7 TeV by MC simulation. The PMTs of the calorimeters were chosen to have <5% deviation from the linear response up to the signal corresponding to a 10 TeV EM shower. Furthermore, the response function of each PMT has been measured with a laser calibration. Taking these calibration data into account, the linear conversion factors based on Fig.4 can be applied up to the LHC energy.

VI. Position Resolution

Shower position is determined using the lateral distribution measured with the position sensors inserted at 4 positions of the calorimeters. Detail performance of the Arm2 silicon strip tracker including the results of the beam test is presented in [8]. Here, we concentrate on the results of the Arm1 SciFi tracker. Because the MAPMT has ∼10% cross talk at maximum, at first, it is corrected using the cross talk matrix determined using the muon beam data. After correcting the relative gain of each channel, the shower position was determined by calculating the gravity center of the 5 channels around the maximum.

'Real' beam position was determined using the ADAMO silicon tracker placed in front of the calorimters. Because the position resolution of ADAMO is far better than the LHCf calorimeters, the r.m.s. of the difference between the positions determined by SciFi and ADAMO is defined as the position resolution of the SciFi tracker. The position resolution of the first SciFi

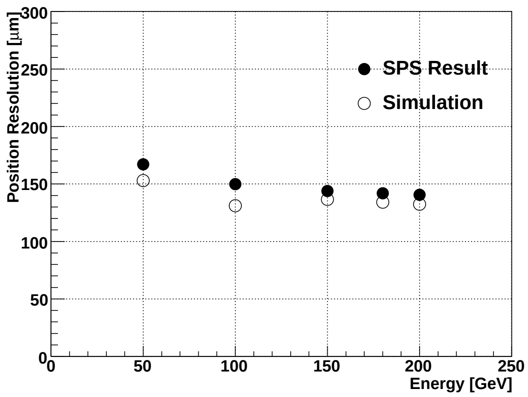

Fig. 5: Position resolution of the Arm1 detector as a function of the incident electron energy. The results for the first X layer are plotted together with the results of MC simulation.

layer in the 20 mm calorimeter is plotted in Fig.5. We find the result satisfies the requirement (<200 μm) and it is less energy dependent than the energy resolution. The experimental result is well explained with the Monte Carlo simulation.

VII. Summary

The performance of the LHCf detectors were tested at the CERN SPS beamline in 2007. Using the data of the electron beam from 50 GeV to 200 GeV, the energy resolution, energy linearity and the position resolution are determined. All results satisfy the requirements of the LHCf experimental design while the energy resolution at the lowest energy end is just at the limit. This can be overcome with an additional operation with a higher PMT gain. Because the statistics of the LHCf experiment is sufficient only with an operation of 10^3 sec at a LHC luminosity of 10^{29} cm^{-2} s^{-1}, some additional operations for calibration and redundacy are in schedule.

Good linearity of the simple energy estimator is validated both with MC and experiment in the SPS energy range. Extension of the experimental linearity to the LHC energy is assured by the calibration of each PMT.

The position resolutions of the SciFi and the silicon trackers (described in [8]) also satisfy the requirement.

The performance presented in this paper are well explained with the MC simulations. Because we concentrated on the response to the electromagnetic showers, the main souces of the uncertainty in the simulation are the actual detector alignment and the electrical noise. The fact that the MC simulations explained the experimental results means that we handle these systematics satisfactory. This assures the reliability of the MC simulations up to the LHC energy. Then we can expect the LHCf can realize the designed physics performance.

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