Current status and plan of the LHCf experiment

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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. The physics goal is to provide data for calibrating the hadron interaction models that are used in the study of very high-energy cosmic-rays. This is possible since the laboratory equivalent collision energy of LHC is 10^{17} eV. Using the two independent detectors containing imaging sampling shower calorimeters, LHCf can determine differential cross sections of π^0's and neutrons in the pseudorapidity range $\eta > 8.4$. These measurements can set critical constraints for the models currently used and to be developed in future. The LHCf detectors are already installed in the LHC tunnel and ready to take data when the LHC starts operation in late 2009. LHCf will complete data taking at the early phase of the LHC commissioning at $\sqrt{s} = 10$ TeV (5×10^{16} eV in labo. frame) in 2009 and come back when the LHC reaches the maximum energy $\sqrt{s} = 14$ TeV.**

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

I. Introduction

After a long debate about the existence of the GZK cutoff [1] [2] in the cosmic-ray energy spectrum at the highest end, recently the Pierre Auger Observatory reported an evidence of the cutoff with an unprecedented exposure [3]. However consistent understanding between the observations of the energy spectrum shape, the chemical composition [4] and the arrival direction [5] is not yet achieved. One of the major sources of this problem is the uncertainty of the hadron interaction when we translate the air shower observations into the primary cosmic-ray properties [6]. Because the energy range of interest exceeds that of the man-made accelerators so far, the hadron interaction models have not been directly tested. To reveal the nature of the primary cosmic-rays and their origin, any tests of the hadron interaction models as high as possible energy is crucial. The 14 TeV center of momentum energy of the Large Hadron Collider (LHC) provides us with the best opportunity to test the models at the laboratory equivalent collision energy up to 10^{17} eV

The LHC forward experiment (LHCf) is one of the six LHC experiments to perform a measurement of the very forward ($\eta > 8.4$) production cross sections of neutral pions and neutrons. Data taking of LHCf is planed at the beam condition of 43 bunch and 10^{10} protons per bunch which is foreseen at the very beginning of the LHC commissioning. At this low intensity and luminosity ($10^{29}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$) 20 minutes of data taking can provide enough statistics to discriminate between hadron interaction models used in the air shower simulations. In this paper, we briefly introduce the experiment and operation plan in the coming years. More detail of the experiment, detectors and their performance are found elsewhere [7] [8] [9] [10] [11] and the other papers presented in this conference [12] [13] [14] [15] [16] [17].

II. The LHCf Experiment

A. Location at LHC

The LHC has massive zero degree neutral absorbers (Target Neutral Absorber; TAN) located ±140 m from interaction points (IP) 1 and 5 . Charged particles from the IP are swept aside by the inner beam separation

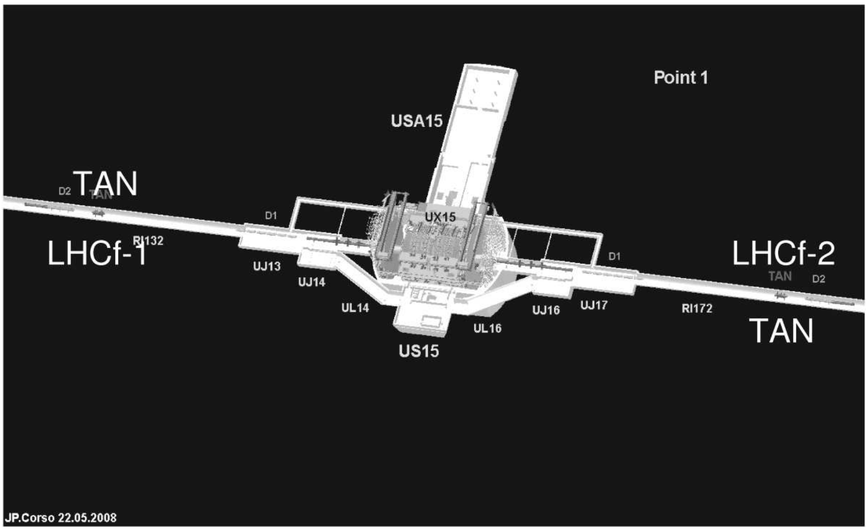

Fig. 1. The layout around the IP1 of LHC. The structure at the center indicates the ATLAS detector surrounding the collision point. The LHCf detectors are installed in the instrumentation slot of the TANs located ±140 m from IP1. Two independent detectors, LHCf Arm1 and LHCf Arm2 are installed at either side of IP1.

dipole D1 before reaching the TAN. Inside TAN the beam vacuum chamber makes a Y shaped transition from a single common beam tube facing the IP to two separate beam tubes joining to the arcs of LHC. In the crotch of this "Y-chamber", there is an instrumentation slot of $96\,\mathrm{mm}^w \times\ 607\,\mathrm{mm}^h \times\ 1000\,\mathrm{mm}^l$ extending from 67 mm below the beam height to the top of the TAN. The LHCf detectors are installed in the slot of the TANs at the ATLAS interaction point (IP1) and measure the neutral particles arriving from the IP (Fig. 1). The aperture for the LHCf measurements is limited by the width of the slot and by the vertical aperture of the beam pipe in the D1 dipole projected to the TAN. This unique location covers the pseudo-rapidity range from 8.4 to infinity.

B. Detectors

LHCf has two independent detectors at either side of IP1 (Arm1 detector and Arm2 detector). Each detector is packed in an aluminum box of $90\,\mathrm{mm}^w \times 620\,\mathrm{mm}^h \times 290\,\mathrm{mm}^l$ that fits to the TAN instrumentation slot (Fig. 2). Each detector has two sampling shower calorimeters in the box with 4 position sensitive layers consisting of scintillating fibers (SciFi) and silicon strip detectors for Arm1 and Arm2, respectively. Details of these trackers are found in [13] [11] [14]. The transverse sizes of the calorimeters are $20\,\mathrm{mm}\times 20\,\mathrm{mm}$ and $40\,\mathrm{mm}\times 40\,\mathrm{mm}$ for Arm1 and $25\,\mathrm{mm}\times 25\,\mathrm{mm}$ and $32\,\mathrm{mm}\times 32\,\mathrm{mm}$ for Arm2. The calorimeters are composed of 22 tungsten plates and 16 plastic scintillators with the total thickness of 44 radiation lengths (1.7 hadron interaction lengths). The longitudinal structure of the calorimeters are shown in Fig. 3. Double calorimeter structure allows to detect gamma-ray pairs produced from π^0 decay. By measuring the energies and positions of the pair, the energy and momentum of the π^0 produced at the collision can be obtained [10] [16].

Both detectors are supported by manipulators in order to have the capability of remotely moving the detectors vertically by a 120 mm stroke. This is to increase the aperture and to avoid radiation when LHCf is not in operation. In front of each detector box, a set of fixed thin plastic scintillators called Front Counter is installed . The FCs cover wider area than the main calorimeters and expected to be a powerful subdetector to reduce beam-gas background events if the residual gas condition is worse than expected. The FCs can also monitor the beam condition even when the main detector is out of the beam plane. Detail of the FC performance is found in [15].

C. Expected Performance

Using the Monte Carlo simulation, the energy resolution of $<5\%$ and the position resolution of $<200\,\mu$m for gamma-rays of >100 GeV are expected. The results of MC simulation are well reproduced in the beam test at CERN SPS in the energy below 200 GeV [12].

Fig. 4 shows the expected energy spectra of single gamma-rays at LHC 14 TeV collisions. Different spectra are predicted by different hadron interaction models used in the cosmic-ray studies. Statistical error bars are assigned assuming occurrence of 10^7 proton-proton inelastic collisions that corresponds to about 10^3 seconds at the luminosity of $10^{29}\,\mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. This is achieved at the very early phase of the LHC commissioning. We can conclude that only with a short operation of LHCf the existing models are clearly discriminated. The expected performances for the π^0 and neutron measurements are found in [16] [17]

D. Status and Plan

The installation of the LHCf detectors in the LHC tunnel has been completed in January and February 2008. Two days after the first beam circulation in the LHC ring on 10 September 2008, the Front Counter of

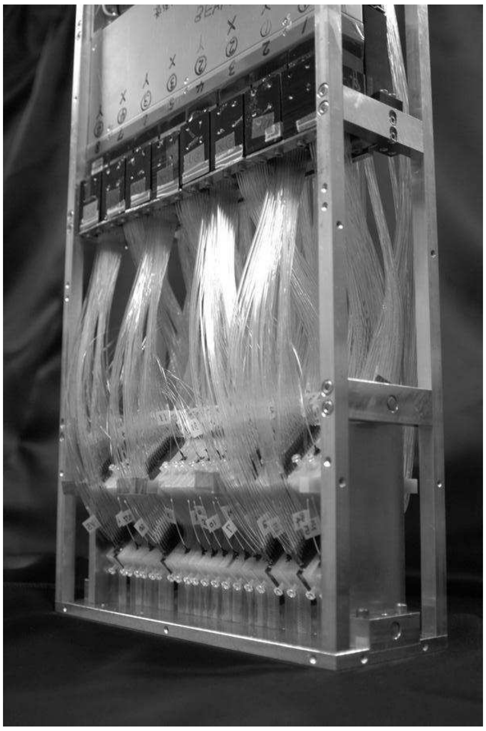

Fig. 2. A photo of the LHCf Arm1 detector.

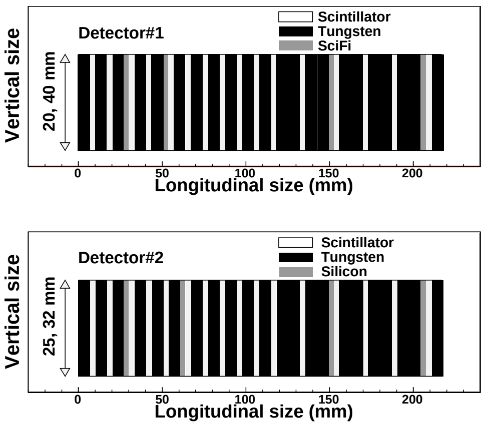

Fig. 3. The longitudinal structure of the LHCf calorimeters. Top (Bottom) panel shows the structure of the Arm1 (2) detector that uses SciFi (Silicon strip detector) as the position sensor.

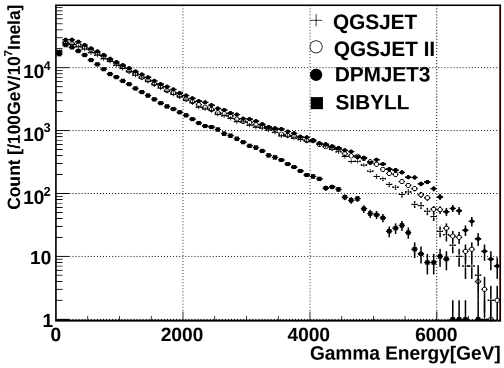

Fig. 4. Expected energy spectrum of gamma-rays measured by one of the LHCf calorimeters. Calculation was performed with four major hadron interaction models used in the cosmic-ray study. The statistical error bars for the operation of 10^3 sec at the luminosity of 10^{29} cm^{-2} s^{-1} are indicated.

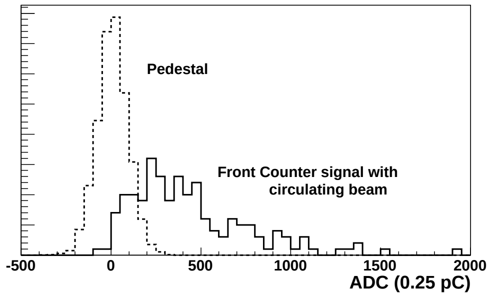

Fig. 5. Beam-gas background observed in one of the LHCf Front Counters during LHC beam commissioning in September 2008. Solid histogram shows the charge distribution of the signal found in the FC faced to the circulating beam while dashed histogram shows pedestal.

the LHCf faced to the circulating beam has detected the signal that was expected from the collisions between the beam and the residual gas in the beam pipe (Fig. 5). Although the LHC met a serious accident a week later and closed for one year, from this short commissioning LHCf has established the synchronization of the data acquisition system with the beam signal.

LHC will restart in late 2009 with the center of momentum energy $\sqrt{s}$ of 10 TeV (5×10^{16} eV in labo. frame). Before accelerating the protons, collisions at 900 GeV (4×10^{14} eV) are also planned. LHCf will take data at both energies during the commissioning of the accelerator when the luminosity is below 10^{29} cm^{-2} s^{-1}. Within one day of operation, LHCf can collect sufficient events including data for calibration and redundancy. The detectors will be removed from the TAN to avoid further radiation damage on the calorimeters. LHC will continue operation at 10 TeV until the end of 2010 to accumulate the integral luminosity for the science of the large experiments. After the 1-year run at 10 TeV, LHC will have a long shutdown to reach the maximum energy of 14 TeV. During the shutdown, the LHCf detectors will be reinstalled in the TAN and take data at the maximum energy when the LHC starts operation.

III. Summary

LHCf is a dedicated experiment at LHC to calibrate the hadron interaction models used for the study of very high-energy cosmic-rays. The experiment is ready and a part of the data acquisition synchronized with the proton beam circulating in LHC was already succeeded in September 2008. LHCf can take data when LHC restarts operation at $\sqrt{s} = 10$ TeV in late 2009. Sufficient amount of data is accumulated during one day of operation. LHCf will also take data at lower energy (900 GeV) before LHC accelerates the particles and at the highest energy (14 TeV) planned after the operation of 10 TeV. The cross sections of π^0's and neutrons at different energies will be crucial calibration points for the interaction models.

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