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Status of the LHCf experiment

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Abstract: The uncertainty of hadron interaction models that are used in Monte Carlo simulations have caused some systematic errors in the energy reconstruction and the determination of composition of ultra high energy cosmic rays. The uncertainty of the models is due to the lack of the experimental data on the nuclear interactions in the energy region over 2×10^{14}eV. The LHCf experiment will provide crucial calibration points at the laboratory equivalent energy of 10^{17}eV, that are indispensable for the hadron interaction models in the ultra-high energy region. The production spectra of photons, neutral pions and neutron will be measured in the very forward region of a LHC interaction point. The first data will be taken during beam commissioning of the LHC with 450GeV+450GeV proton-proton collisions, which is scheduled to start at the end of 2007. The data set will be taken with 7TeV+7TeV collisions, corresponding to 10^{17}eV cosmic ray collisions in the laboratory frame. The LHC is scheduled to start 7TeV+7TeV collisions in the Spring of 2008. In the meantime the preparation of the LHCf experiment is ongoing. The Arm#1 detector was fully assembled in July 2006. The Arm#2 detector was fully assembled in April 2007.

Introduction

Knowledge of the energy distribution of particles emitted in the very forward region in hadron interactions is critically important for understanding of the high energy cosmic ray phenomena. However so far only UA7 experiment at the CERN SPS has obtained data in the energy range exceeding 10^{14}eV [1]. The lack of experimental data in the high energy range over 10^{15}eV has caused the uncertainty of hadron interaction models that are used in Monte Carlo simulations of atmospheric shower due to high energy cosmic rays.

Existence of the GZK cut-off is one of the most important theme in the cosmic ray physics. The uncertainty of models makes it difficult to determine the energy spectrum of ultra high energy cosmic rays over 10^{19}eV with high precision. For example, the AGASA collaboration reported that the systematic error of energy reconstruction due

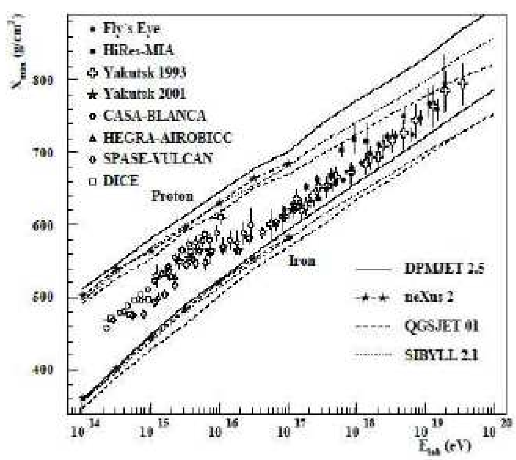

Figure 1: The position of the shower maximum X_{max} is shown as a function of the primary cosmic ray energy [3]. The thick line corresponds to the prediction by the DPMJET2.5 model for iron primaries and proton primaries, while the dashed dotted curve represents the predictions by the QGSJET model. The dotted line reflects the prediction by the SIBYLL2.1 model.

to interaction models is 10% [2]. In addition, the uncertainty gives different results for the chemical composition of cosmic rays in the 10^{17}eV range [3] (Figure.1).

Now the Large Hadron Collider (LHC), which is the largest and the most powerful hadron accelerator in the world, is under construction at CERN. In 2008, The LHC will give us the knowledge of hadron interaction in the very high energy range of 10^{17}eV.

The LHCf experiment

The LHCf is a physics experiment to use the LHC, where proton-proton collisions at 7TeV+7TeV corresponding to $1{\times}10^{17}$eV in the laboratory system. The LHCf will measure the energy and transverse momentum spectra of neutral particles produced in the very forward region of a LHC interaction point.

The LHCf apparatus is composed of two independent detectors for background rejection and redundancy, that are installed +/- 140m from the

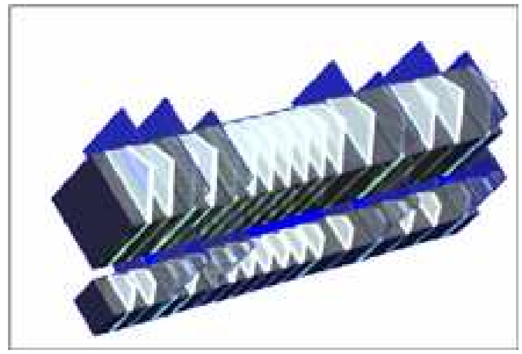

Figure 2: A schematic view of the calorimeters in Arm#1 detector. The each LHCf detector has 2 independent calorimeter towers with different cross section for separately measuring two photons from a neutral pion decay.

Interaction Point 1(IP1). Each of the detectors (Arm#1 and Arm#2) has two sampling and imaging calorimeters made of tungsten layers (total depth is 44 radiation length and 1.6 interaction length), 16 plastic scintillator layers and 4 position sensitive layers (Fig.2). The transverse cross-sections of the two calorimeters in Arm#1 are 20x20mm and 40x40mm, and that in Arm#2 are 25x25 mm and 32x32 mm. Four position sensitive layers, which are made of 1mm x 1mm scintillation fibers for Arm#1 and microstrip silicon sensors (80 μm implantation pitch, 160 μm readout pitch) for Arm#2 , measure the transverse position and the lateral profile of the showers. The two independent calorimeters with the position sensitive layers allow to measure photon pairs from π^0 decay.

The LHC has zero degree neutral absorbers (TAN) +/- 140m from IP1 where the ATLAS detector is installed. Inside the TAN, the beam pipe makes a transition from a single large diameter pipe to two small diameter pipes jointing to the arcs of the LHC (Y-chamber). A 96mm(w) x 1000mm(l) x 603mm(h) slot of the TAN allows to insert the LHCf detector between small beam pipes for measuring the production spectra of neutral particles at zero degrees collision angle. The LHCf detector will cover the rapidity range $>$ 8.4 in a zero beam crossing angle run and $>$ 8.7 in a 140μrad beam crossing angle run.

Expected Performance of LHCf

The expected performance of the detectors has been studied by using MC simulations. The expected energy resolution of the detectors is 6% for photons with 100GeV and 3% for photos with 1TeV. The expected energy resolution for neutrons is 30% for the showers initiated at early stages of the calorimeters. The position resolution is less than 200μm.

Expected physics performance has been studied. Figure.3 shows the energy distribution of photons as measured with the Arm#1 20x20 mm calorimeter which are located at the center of neutral particle flux. They are simulated by using various interaction model, DPMJET3, QGSJET1, QGSJET2 and SIBYLL with 5% energy resolution. The SIBYLL model gives a softer spectrum than the other models. Combining with the information of the energy spectra of photons measured by the 40x40 calorimeter and neutrons, we are able to discriminate the models clearly. The expected event rate of background due to collisions of proton beams with residual gas in the beam pipe is 2 orders lower than that of proton-proton collisions. In the case of high background level that is possible at the early stage of the LHC commissioning, the energy distribution of neutral pions reconstructed from photon pairs is much useful for discrimination of the interaction models. The detail is described in the “Technical Design Report of the LHCf experiment” [4].

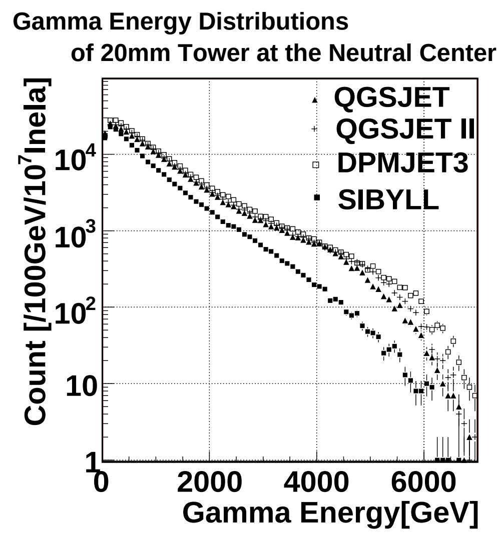

Figure 3: the expected energy distribution of gamma rays as measured at 20mm calorimeter of Arm#1. 5% energy resolution over all range has been taken into account. The each maker show the distribution of DPMJET3, QGSJET1, QGSJET2 and SIBYLL models.

Status of the LHCf experiment

The detectors has been completed (Arm#1 in July 2006 and Arm#2 in April 2007, Figure.4). Each detector was once installed in the TAN which are placed +/-140m far from IP1 inside the LHC tunnel (Arm#1 in January 2007 and Arm#2 in April 2007) and removed after some tests for baking the TAN. Finally the detectors will be installed in the TAN in September 2007.

The performance of detectors has been evaluated by beam tests at CERN SPS. The first beam test was carried out with a prototype detector in August 2004. By the beam test, the energy resolution, position resolution and the e/p separation were checked by the electron beams with 50-200GeV and the proton beams with 150 and 350GeV. The result were in good agreement with MC simulations [5]. The second beam test was carried out layer at August 2006 with the fully assembled Arm#1 detector and the partially assembled Arm#2 detector which has full tungsten and scintillator layers and only one microstrip silicon detector. In Aug-Sep 2007, a final beam test will be carried out at CERN SPS with the completed detectors.

In the end of 2007, the LHC will start. The LHCf operation is planned in 4 phases. ”Phase-0” is operation during the LHC engineering run in the end of 2007. In this period, proton-proton collisions at 450GeV+450GeV are planned. It corresponds to 4×10^{14}eV in the laboratory system. The energy is two orders lower than the energy of 7TeV-7TeV collisions. However, it is near the “Knee” region in galactic cosmic ray spectrum. So, the data obtained will be a important calibration point for hadron interaction models in the simulations of high energy cosmic ray air showers. The ”Phase-1” operation is planned during the LHC beam com-

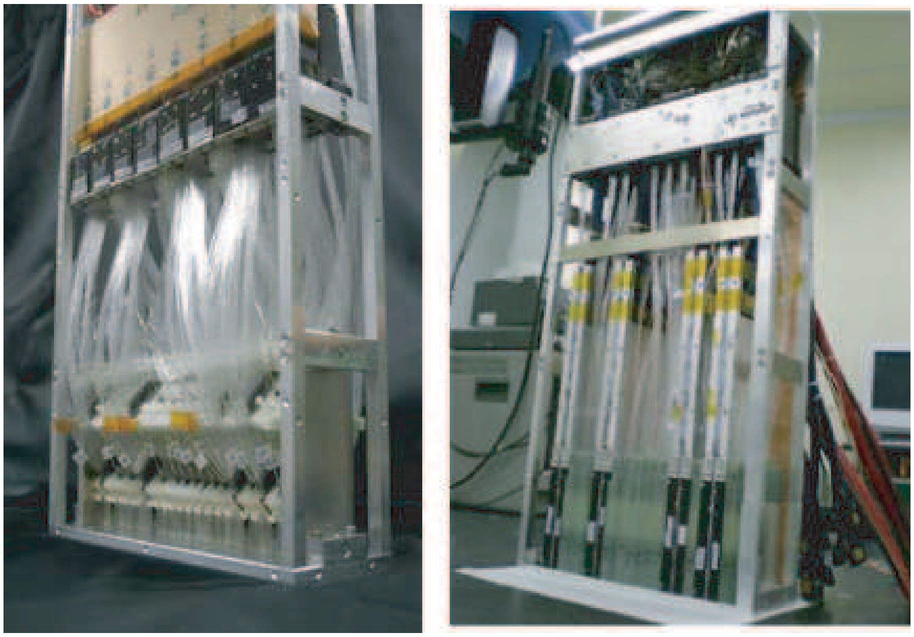

Figure 4: Left: the Arm#1 detector, which has been completed in July 2006. It has the tungsten plates with total length of 44 X_0 and 1.6 λ_I, 16 scintillator layers and 4 X-Y scifi layers at 6, 10, 30, 42 X_0 . Right: Arm#2 detector, which has been completed in April 2007. It has 4 X-Y microstrip silicon layers at 6, 12, 30, 42 X_0 instead of the scifi layers.

missioning at 7TeV+7TeV in the middle of 2008. In the operation with luminosity at 10^{29}/cm^2/s and 43 bunches , we need only a few days of measurements of photon and neutron events, to discriminate the hadron interaction models clearly. In the future, "Phase-2" operation is planned with TOTEM, which is a physics experiment for measuring the total absolute cross section, and "Phase-3" operation is planned at heavy ion run.

Summary

The LHCf is a physics experiment to be performed during the early commissioning time and the operation of the CERN Large Hadron Collider. The detectors have been completed and tested at CERN SPS. From the end of 2007, the LHCf experiment will measure the energy and transverse momentum spectra of neutral particles in the very forward region in very high energy hadron interaction over 10^{14}eV. It will be indispensable for calibration of the simulation of high energy cosmic ray air showers.

References

[1] E. Pare, et al., Inclusive production of π^0's in the fragmentation region at the S—=ppS collider, Physics Latters B 242 (1990) 531–535.

[2] M. Takeda, et al., Energy determination in the Akeno Giant Air Shower Array experiment, Astroparticle Physics 19 (2003) 447–462.

[3] J. Knapp, D. Heck, S. S. J., D. M. T., M. Risse, Exensive air shower simulations at the highest energies, Astroparticle Physics 19 (2003) 77–99.

[4] Technical Design Report of the LHCf experiment CERN-LHCC-2006-004.

[5] T. Sako, et al., Parformance of the prototype detector for the LHCf experiment, NIM in press.