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Current status of the LHCf experiment and future plan

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Abstract. The Large Hadron Collider forward (= LHCf) experiment has successfully finished the first phase of data taking at LHC $\sqrt{s} = 0.9$ and 7 TeV proton-proton collisions in 2010. As current status, we concentrate on analyzing the obtained data. As the first result, the energy spectra of photon measured by LHCf during = 7 TeV p-p collision has been published recently. Also the study of the upgraded version of LHCf detector for future = 14 TeV run scenario is developed with the GSO scintillator. Another possible plan of p-A(nuclear) collision in LHC is also studied. In this paper, as the current status of the experiment, analyses, and works for foreseen detector upgrade are summarized.

1. INTRODUCTION

The LHCf experiment[1, 2] is one of the LHC forward region experiments dedicated to the cosmic ray physics. Because we can only observe the UHECRs by indirectly way with particle cascade(called air-shower), we have to care about systematic errors caused by the air-shower development. To measure the particles emitted in the forward region it is important to understand the cosmic ray interactions as verification of the models. However, currently the models were verified up to 10^{14} eV by the UA7 [3] experiment at the CERN-SPS. On the other hand, the LHCf experiment is designed to obtain data with a energy corresponding to 10^{17} eV in cosmic-ray energy (equivalent to 14 TeV in collision energy).

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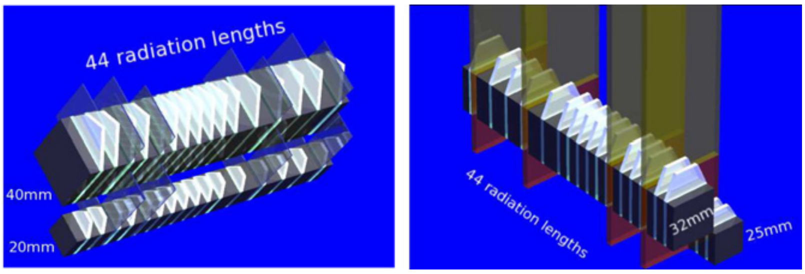

Figure 1. *Left*: Arm1 detector, *Right*: Arm2 detector.

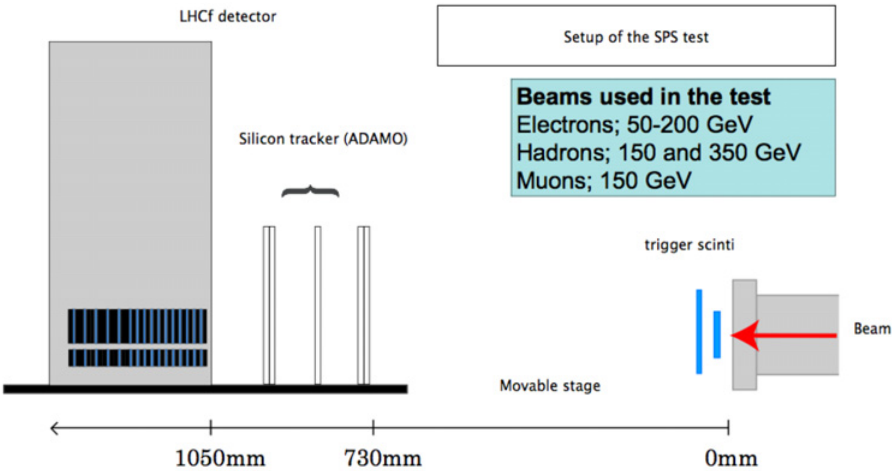

Figure 2. Set up of the beam test.

The physics target is to provide energy and transverse momentum spectra of particles emitted to the forward region of the LHC interaction point (IP1). It will be expected to reduce the uncertainty of the model dependence close to the UHECR energy.

1.1 The LHCf Detector

Two independent detectors called "Arm1" and "Arm2" were installed ±140m away from LHC IP1 (ATLAS). Figure 1 shows a schematic picture of the LHCf detectors. Each detector has two calorimeter towers composed of 44 r.l. of tungsten plates, 16 sampling layers of plastic scintillators, and four X-Y pairs of lateral position sensitive detectors (SciFi in Arm1 and silicon strip detector in Arm2). The responses of the LHCf detectors for high energy particles were studied in the fixed target experiments using electron beams below 220 GeV, proton beams below 350 GeV and muon beams below 150 GeV [4]. The performance for electromagnetic showers up to equivalent to 3.5 TeV are well understood using the Monte Carlo simulations.

1.2 The study of the LHCf detectors

Energy resolution and linearity of the LHCf calorimeters for electromagnetic showers were measured at the SPS H4 beam line in 2007 using electron beams of 50-200GeV and muon beams of 150 GeV[4]. Figure 2 shows the setup of the beam test.

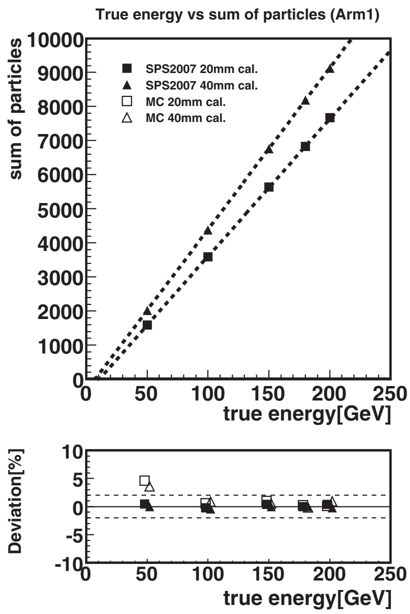

Figure 3. Energy linearity obtained from the beam test (upper). Deviation from the linear fitting (lower).

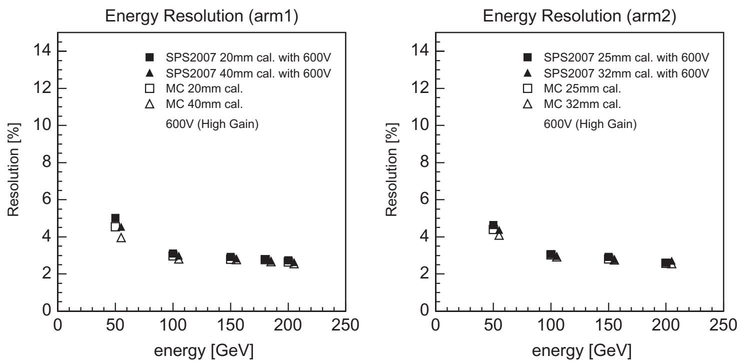

Figure 4. Energy resolution of the Arm1 (left) and Arm2 (right) detector for electro magnetic incidents.

Particle incident position was measured with an external silicon strip detector (ADAMO) placed in front of the LHCf calorimeters.

The energy linearity was obtained as shown in Fig. 3. This figure shows the summation of shower particles as function of the beam energy. Linear fits to the beam test data and residuals from the fits are also shown. A deviation from linearity is less than 2% in the beam test data (filled markers) and shows good agreement between the data and MC simulations (open markers) except at 50 GeV.

Figure 4 shows the energy resolution obtained by beam test and MC simulations [4]. The absolute energy scale was determined in these data.

Lateral hit position resolutions were also obtained as below 200 μm for Arm1 detector and below 60 μm for Arm2 detector by the beam test. The results that were obtained ($<5\%$ energy resolution and $<200\mu$m (60μm) for Arm1(Arm2) position resolution) are well understood by using MC simulations and good enough for the requirements of the LHCf experiment.

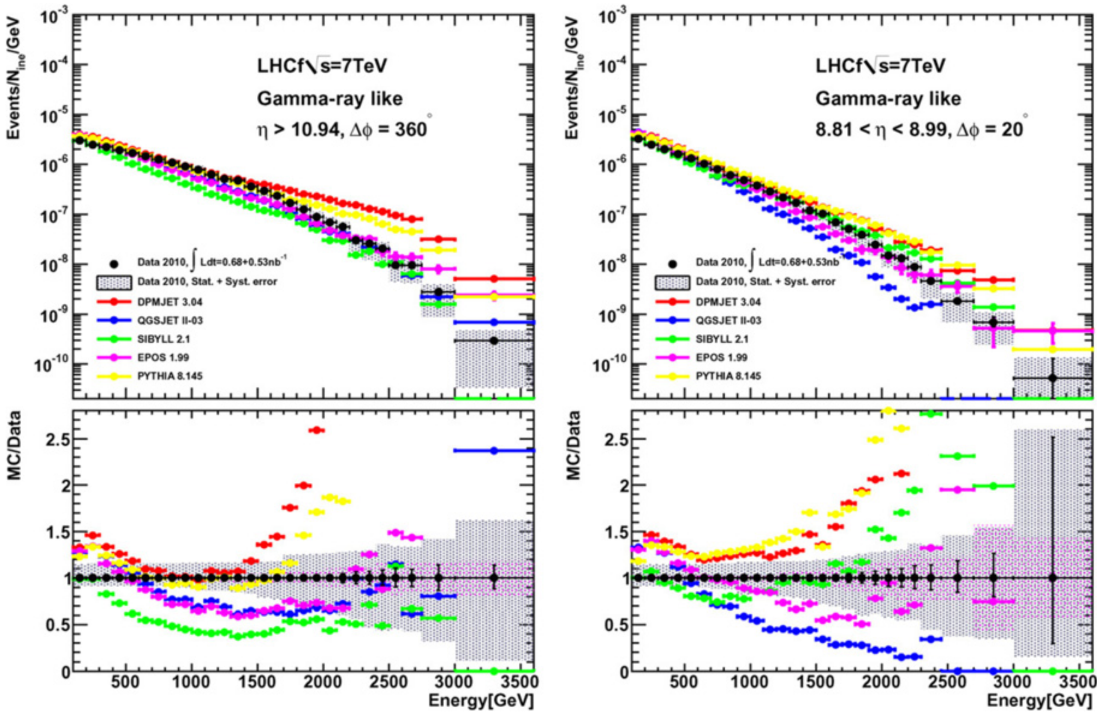

Figure 5. Energy spectra of the photon observe in LHCf detectors. Left(Right) panel shows the spectra of Arm1(Arm2). lower panel shows the MC spectra divided by its data.

2. THE PHYSICS RESULTS

2.1 Photon spectra at $\sqrt{s} = 7$ TeV

The LHCf experiment has successfully measured the energy spectra of photon emitted in the very forward region of the LHC proton-proton collisions in 2010. We compared the results of $\sqrt{s} = 7$ TeV collision at the LHC with the several hadronic interaction models used in cosmic ray observations. Figure 5 shows the energy spectra of data and MC simulations.

No model is able to describe completely the experimental data. The Data used in this analysis was obtained on 15 May 2010 during proton-proton collisions at $\sqrt{s} = 7$ TeV with zero degree beam crossing angle (LHC Fill 1104). The total luminosity of the three crossing bunches in this fill was $L = (6.3 - 6.5) \times 10^{28}$ cm^{-2}s^{-1}. The ranges used for the small calorimeters and the large calorimeters are [$\eta > 10.94$, $\Delta\phi = 360.0$] and [$8.99 > \eta > 8.81$, $\Delta\phi = 20.0$], respectively. Only single hit events were selected in this analysis. The result was summarized in [5].

3. UPGRADE WITH GSO SCINTILLATOR

The LHCf detectors will be upgraded with GSO scintillators for the coming $\sqrt{s} = 14$ TeV run (for more radiation hardness) due to the radiation resistibility. Figure 6 shows a EJ260 scintillator (currently used) and GSO scintillator.

Gd_2SiO_5(GSO) scintillator has very excellent radiation resistance, a fast decay time and a large light yield. The radiation hardness of GSO and its optical characteristics have been measured with Carbon ion beams at the Heavy Ion Medical Accelerator in Chiba (HIMAC). After exposure of 7×10^5 Gy, the

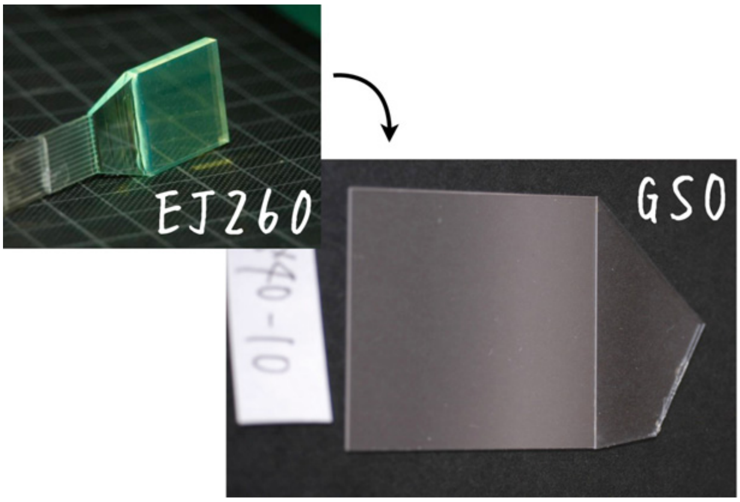

Figure 6. We replace scintillators from EJ260 to GSO for more radiation hardness.

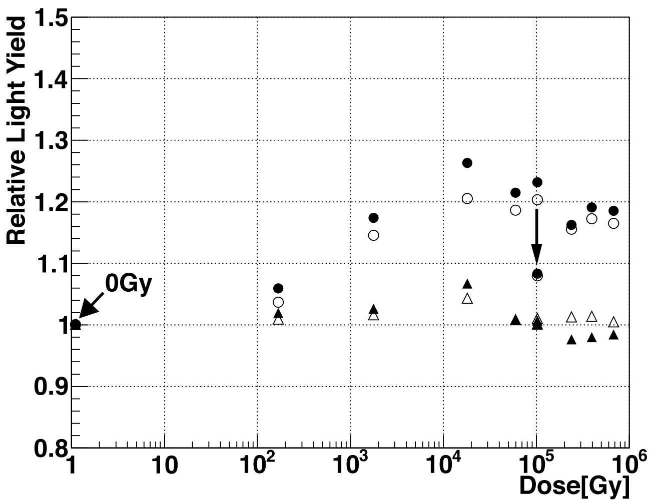

Figure 7. Stability of light yield of GSO scintillator under radiation exposure. Horizontal axis shows exposed dose and vertical shows relative light yield of GSO.

light yield of GSO scintillator did not decrease, but rather an increase up to about 25% was observed [6]. Figure 7 shows the stability of light yield of GSO scintillator under radiation exposure.

4. FUTURE PLAN

4.1 Analysis

Now we concentrate the following analyses for topics such as neutral pions, 900 GeV photons, and P_t distribution of photons and hadron spectra at 7 TeV collisions. We also are working the analyses for impact on air shower calculation for CR physics.

4.2 Measurement

We are preparing for foreseen data acquisitions with the proton-ion collision in 2012, and the p-p collisions at $\sqrt{s} = 14$ TeV in 2014 [7].

4.3 Research and development

The first GSO-LHCf detector will be constructed in summer 2012 and tested using CERN-SPS beams.

5. SUMMARY

The LHCf experiment is dedicated to cosmic-ray physics and successfully finished the 1st phase of data taking at 2010. The energy spectra of photon at $\eta > 10.94$ and $8.81 < \eta < 8.99$ at $\sqrt{s} = 7$ TeV have been obtained and compared with several hadronic interaction models. None of the models agrees perfectly with data. Other analyses such as π^0 spectra, photon spectra at 0.9 TeV, hadron spectra, P_t distribution, wider η coverage, etc are also ongoing. LHCf is also assured to take data at 14 TeV (or at the maximum LHC energy) collisions foreseen after the long shutdown. Detectors will be upgraded with GSO scintillators for the coming highest energy run. Additional possibility to take data at p-A and A-A collisions is also in study to infer the nuclear effect or directly simulate CR-air interaction. Using both existing data and future experiments, LHCf will provide crucial data to constrain hadron interaction models and improve the interpretation of UHECR observations.

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