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Early Physics Results of the LHCf Experiment

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The LHCf experiment at LHC has been designed to calibrate the hadron interaction models used in High Energy Cosmic Ray (HECR) Physics through the measurement of the forward neutral particle produced in p-p interaction. The uncertainty caused by the poor knowledge of the interaction between very high energy primary cosmic ray and the earth's atmosphere prevents the precise deduction of astrophysical parameters from the observational data those causing the most important source of systematic error in HECR dedicated experiments. A calibration of the energy scale in the $10^{15} \div 10^{17}$ eV energy range accessible to LHC provides crucial input for a better interpretation of primary cosmic ray properties. In this paper, the status of the LHCf experiment with special emphasis to the first Physics results is discussed.

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1. Introduction

Dedicated extensive air shower experiments are in place since many years and have strongly contributed to our understanding of High and Ultra High Energy Cosmic (UHECR) Ray Physics. Recently, in particular, the Pierre Auger Collaboration [1] and the Telescope Array Collaboration [2], thanks to the excellent performance of their hybrid detector arrays are providing us new exciting observations of UHECRs. Although these recent results have brought a deeper insight in primary cosmic ray properties, still they are largely affected by the poor knowledge of the nuclear interactions in the earth's atmosphere. This is true, for instance, for the interpretation of the behaviour of the energy spectrum in the UHE region and the chemical composition of cosmic rays. Accelerator experiments validating the interaction model chosen are hence essential. The Large Hadron Collider (LHC) offers a unique opportunity to take data at energies ranging from $\sqrt{s} = 0.9$ TeV up to 14 TeV, thus covering the region between the "knee" and the GZK cut-off. The LHCf experiment has been designed to measure the energy and transverse momentum spectra of neutral particles (gamma-rays, π^0 s and neutrons) emitted in the very forward region (pseudo-rapidity $|\eta| > 8.3$) of LHC collisions. As a matter of fact air shower development is dominated by the forward products of the interaction between the primary particle and the atmosphere. LHCf measurements are hence essential to a proper calibration of hadron interaction models used in air shower simulations in the energy range accessible at LHC.

2. The LHCf experiment

LHCf is the smallest of the LHC experiments. The detector consists of a double arm – double tower sampling and imaging calorimeter, placed at ± 140 m from ATLAS interaction point (IP1) inside the zero-degree neutral absorbers (Target Neutral Absorber, TAN). Charged particles from the IP are swept away by the inner beam separation dipole before reaching the TAN, so that only photons mainly from π^0 decays, neutrons and neutral kaons reach the LHCf calorimeters.
Each calorimeter tower is made of 16 layers of plastic scintillators interleaved by tungsten layers as converter, complemented by a set of four X-Y position sensitive layers which provide incident shower positions, in order to obtain the transverse momentum of the incident primary and to correct for the effect of leakage from the edges of the calorimeters. The total thickness is 44 r.l. and 1.7 interaction lengths.
The two calorimeters slightly differ for the geometrical arrangement of the two towers and for the position sensitive layers made by 1 mm^2 scintillating fibers in one calorimeter (ARM1) and silicon micro-strip layers in the other (ARM2). A detailed description of the LHCf detector and performance can be found in [3].

3. Data taking and preliminary results at 900 GeV pp collisions

At the end of November 2009 LHC has started to provide collisions to the experiments at 900 GeV center of mass energy. The LHCf experiment has taken data from December 6 till December 15, accumulating about 2800 and 3600 shower triggers in ARM1 and ARM2 detectors, respectively. 900 GeV data have been accumulated also in a second run during spring 2010. Because the

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luminosity of the operations in 2010 was about 15 times higher than that in 2009, the LHCf experiment has taken about 10 times more statistics data, 4.4×10^4 and 6.3×10^4 shower events in ARM1 and ARM2 respectively. A preliminary analysis has been carried on to reconstruct γ and hadron spectra. The particle identification has been achieved through the use of transition curve information. To parameterize the transition shape of a shower, we defined the L90% variable, which is the longitudinal position containing 90% of the summation of the shower particles. In this preliminary analysis, we discriminate between gamma-ray like events and hadron like events requiring L90% to be less than $16 + 0.0002 \times dE$ r.l., where dE is the total energy deposit normalized by MIP and it is about 4,000 when a gamma-ray with 100GeV hits the calorimeter.

Figure 1 shows the measured spectra of gamma-ray like and hadron like events after subtraction of the beam-gas background. The black dots are data while the colored dots show the spectra expected by different MC models widely used in HECR Physics, DPMJET3 [4], QGSJET1 [5], QGSJET2 [6], SYBILL2.1 [7] and EPOS1.99 [8], which are normalized by total entries of gamma-ray like and hadron like events. The analysis is well advanced but still not finalized and, at this stage, only statistical errors are reported in the plots. A detailed investigation of systematic uncertainties is under study. Furthermore, in the spectra for hadron like events only the gamma-ray equivalent energy are used instead of reconstructed hadron energy.

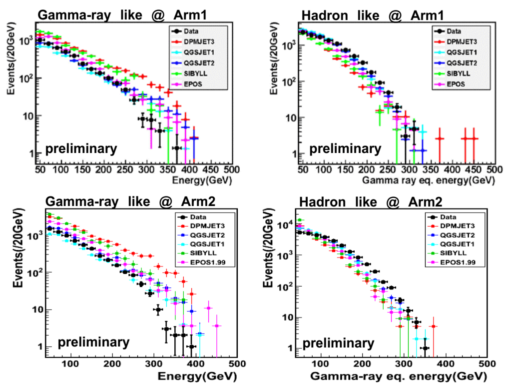

Figure 1: Energy spectra for gamma-ray like and hadron like events measured by ARM1 (top) and ARM2 (bottom) detectors in 900 GeV pp collisions compared with the expectation of main Monte Carlo models.

4. Data taking and preliminary results at 7 TeV pp collisions

Since 30 March 2010 till mid of July, the LHCf experiment has taken data at 7 TeV center of mass energy. The detector has been designed to cope with low luminosity ($< 10^{31}$ cm^{-2}s^{-1}) run due to the radiation damage suffered by the plastic scintillators it is made of. For this reason, once the LHC luminosity exceeded the LHCf design tolerance, the detector has been removed from the TAN region. One important difference between 900 GeV and 7 TeV data taking is the possibility to reconstruct π^0 emitted in the forward region of p-p collisions at 7 TeV. This is a fundamental tool for the absolute energy scale calibration. Mass resolution of about 4.5% and 2.3% for ARM1 and ARM2 respectively have been achieved. Results at 7 TeV have yet not been finalized however gamma-ray and hadron like spectra are already available for a subset of the collected data (about 2%). Figure 2 shows the reconstructed energy spectra of gamma-ray like and hadron like events measured by Arm1 and Arm2 detectors. Also in this case, only statistical errors are shown. Comparison with MC models are in progress.

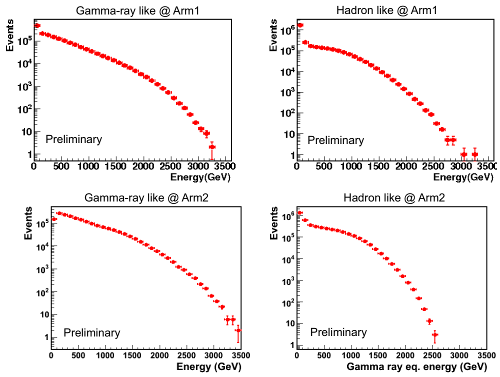

Figure 2: Energy spectra for gamma-ray like and hadron like events measured by ARM1 (top) and ARM2 (bottom) detectors in 7 TeV pp collisions. Only statistical errors are shown.

5. Conclusions

The LHCf experiment has smoothly taken data at LHC both at 900 GeV as well at 7 TeV center of mass energy till mid of July when it was removed from the LHC tunnel. The detector will be upgraded to improve its radiation hardness and will be reinstalled when LHC will provide 7+7 TeV p-p collisions.
Thanks to the excellent detector performance, LHCf will be able to calibrate air shower Monte Carlo codes covering the most interesting energy range for HECR Physics, thus providing invaluable input to the understanding of high energy phenomena in the Universe.

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