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The LHCf experiment at LHC

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Summary. — High Energy Cosmic Ray experiments are providing useful information to understand high energy phenomena in the Universe. However, the uncertainty caused from 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. The Large Hadron Collider (LHC) provides the best opportunity for calibrating the hadron interaction models in the most interesting energy range, between 10^{15} eV and 10^{17} eV. To constrain the models used in the extensive air shower simulations the measurements of very forward particles are mandatory. Among the LHC experiments, the LHCf experiment has been designed to reach this goal and its capability to measure forward neutral particle produced in p-p interaction will result crucial for a better interpretation of cosmic ray studies. In this paper, the status of the LHCf experiment and preliminary results for 900 GeV data taking are discussed.

PACS 13.85.Tp – Cosmic-ray interactions.
PACS 29.40.Vj – Calorimeters.

1. – Introduction

LHCf is the smallest of the LHC experiments. It has been designed to study neutral particles produced in proton-proton collisions at LHC in the very forward region, covering the $|\eta| > 8.3$ pseudo-rapidity region. 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.

While the two calorimeters are identical for the calorimetric structure, they slightly differ for the geometrical arrangement of the two towers and for the position-sensitive layers made by 1 mm^2 scintillating fibres in one calorimeter and silicon micro-strip layers in the other. A detailed description of the LHCf detector can be found in [1].

The LHCf experiment differs from the other LHC experiment not only in dimensions but also for the main physics motivation, which for LHCf is strictly connected to astroparticle physics. The goal of the experiment is indeed to measure neutral particle spectra to calibrate Monte Carlo codes used in High Energy Cosmic Ray (HECR) physics. A good knowledge of nuclear interaction model of primary cosmic rays with the Earth's atmosphere is mandatory to better understand many properties of primary cosmic rays, like the energy spectrum and the composition, whose knowledge is finally strictly related to our capability to understand the origin of high energy phenomena in the Universe. Dedicated extensive air shower experiments have been taking data for many years and have strongly contributed to our understanding of High and Ultra High Energy Cosmic Ray (UHECR) physics. However, the results of these experiments are in some cases not fully in agreement and, in addition, the interpretation of their data in terms of primary cosmic ray properties is strongly affected by the 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, in particular the existence of events above the so-called GZK cut-off, and the chemical composition of cosmic rays. Indeed, evidence of UHECR, above the GZK cut-off, has been reported for the first time by the AGASA experiment [2]. On the contrary, the results of the HiRes [3] experiment and, more recently, the ones of the Pierre Auger Collaboration [4] are consistent with the existence of the cut-off. The disagreement among data would be reduced by adjusting the energy scales of the different experiments to account for systematic effects in the determination of the particle energy, that might be due to different detecting techniques. Similar considerations hold for the interpretation of cosmic ray composition since it is directly related to their primary sources. Accelerator experiments validating the interaction model chosen are hence essential. As a matter of fact air shower development is dominated by the forward products of the interaction between the primary particle and the atmosphere. The only available data on the production cross-section of neutral pions emitted in the very forward region have been obtained more than twenty years ago by the UA7 Collaboration [5] at the CERN Sp$\overline{\text{p}}$S up to an energy of 10^{14} eV and in a very narrow pseudo-rapidity range. The LHCf experiment at LHC has the unique opportunity to take data at energies ranging from $\sqrt{s} = 0.9$ TeV up to 14 TeV, thus extending significantly the energy range up to a region of great interest for high energy cosmic rays, the region between the "knee" and the GZK cut-off.

2. – Physics performances

In order to calibrate the Monte Carlo codes used in HECR physics, the LHCf experiment should be able to have a detailed knowledge of the energy scale. For this reason LHCf relies on a very precise reconstruction of the π^0 mass, by reconstructing in the two towers the showers from the 2 γ from π^0 decays.

The performances of the detector have been carefully measured using beam test data and well satisfy the design requirements [6]. The measured energy resolution for the calorimeters is better than 4% at 200 GeV, while the position resolution in locating the shower center for particles above 100 GeV (which is the region of interest for LHCf)

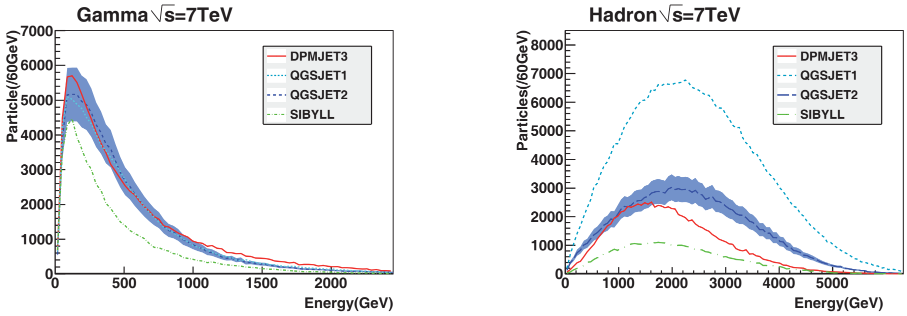

Fig. 1. – Expected energy spectrum for photons (left) and neutral hadrons (right) according to different interaction models at $3.5 + 3.5$ TeV center-of-mass energy p-p collisions.

is about $200\,\mu$m for scintillating fibre layers (ARM1) and about $50\,\mu$m for the silicon micro-strip layers (ARM2).

Figure 1 shows LHCf expectations for the γ and neutron energy spectra for few minutes exposure at $10^{29}\,\text{cm}^{-2}\,\text{s}^{-1}$ with 3.5+3.5 TeV center-of-mass energy p-p collisions. Depending on the nuclear interaction model used, the energy spectra change more or less significantly. As can be seen from this plot, the LHCf experiment will be able to disentangle different interaction models already at lower energy and with very low statistics, thus ensuring a calibration of cosmic ray Monte Carlo in an energy range wider than the one expected at the beginning of the project.

3. – Data taking and preliminary analysis

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 6500 shower triggers in total on both arms of the calorimeter. A typical γ event registered on ARM2 detector is shown in fig. 2.

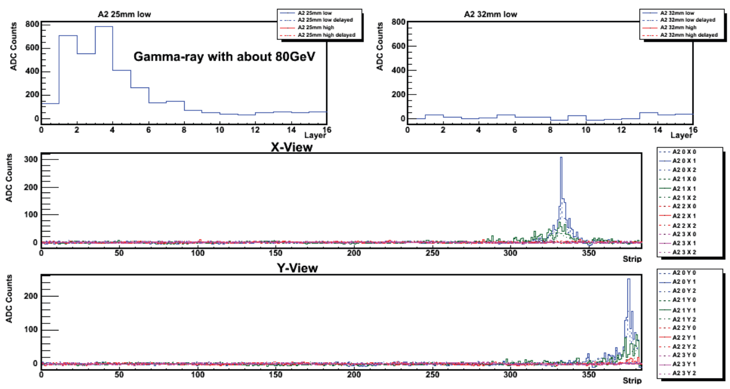

Fig. 2. – A typical γ event registered on ARM2 detector in 900 GeV collision data. The two upper panels show the longitudinal energy profile deposited on each tower of the calorimeter, while the two lower panels show the transverse energy X and Y profile deposited on each of the four silicon layers.

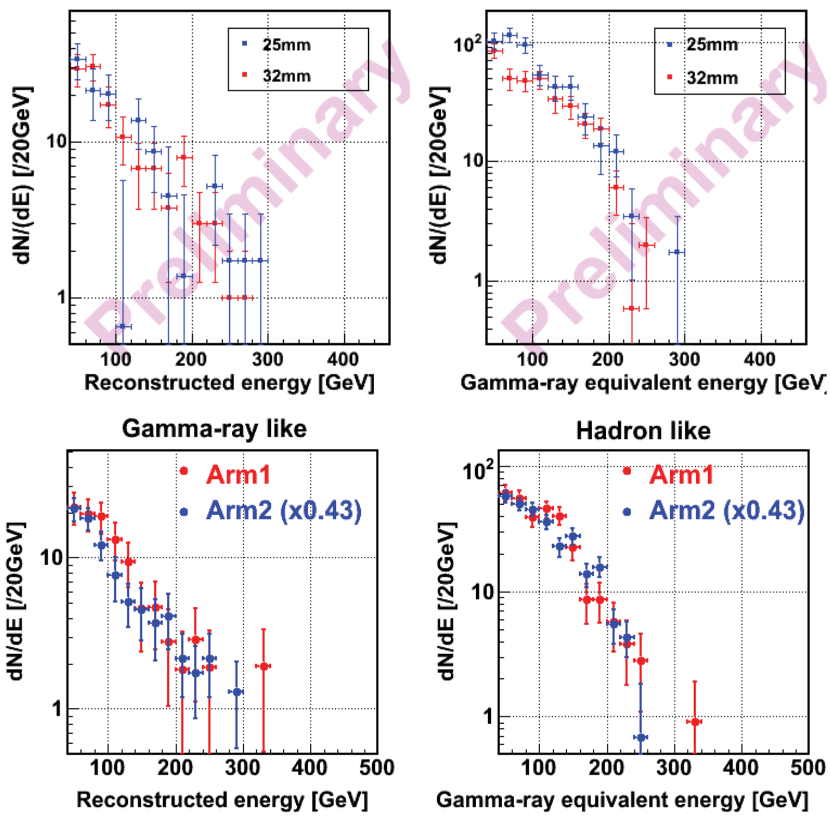

Fig. 3. – Comparison of reconstructed γ and hadron spectra in small and large tower of ARM2 detector (upper plots) and in ARM1 and ARM2 detector (bottom plots) for 900 GeV p-p data. Spectra are normalized to take into account different geometrical acceptance.

A preliminary analysis has been carried out to reconstruct γ and hadron spectra. The particle identification has been achieved through the use of transition curve information. Results obtained in the two towers as well as in the two arms are consistent with each other both for photons and hadrons as can be seen from fig. 3.

Also in a second run during spring 2010, 900 GeV data have been accumulated and the whole analysis of the events collected in 2009 and 2010 is ongoing and almost ready for publication. LHCf is now taking data at 7 TeV center of mass energy. At this energy the experiment is able to reconstruct π^0 events. A π^0 candidate event collected in ARM2 detector is shown in fig. 4.

Due to radiation damage issue the LHCf experiment will stop its data taking once the LHC luminosity will be above $10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ or once the integrated luminosity will be above $2\,\mathrm{pb}^{-1}$. The detector will be hence removed from the TAN and will be upgraded to cope with higher luminosity and will be reinstalled when the LHC 14 TeV run will start.

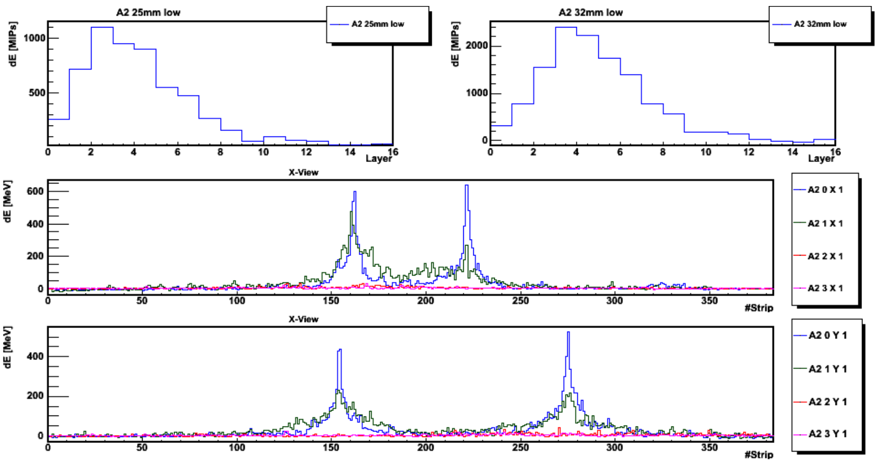

Fig. 4. – A π^0 candidate event registered on ARM2 detector in 7 TeV collision data. The plots follow the same convention as in fig. 2.

4. – Conclusions

The LHCf experiment is actually taking data at LHC both at 900 GeV as well at 7 TeV center-of-mass energy. When the luminosity exceeds $10^{31}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ the detector will be removed to upgrade its radiation hardness and will be reinstalled when LHC will provide 7+7 TeV p-p collisions.

Thanks to the excellent detector performance for the reconstruction of photon, neutral meson and neutron spectra at different energies from 900 GeV up to 14 TeV proton runs, 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 our understanding of high energy phenomena in the Universe.

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