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First results from LHCf for forward physics in $\sqrt{s} = 7\,\text{TeV}$ proton-proton interactions

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Summary. — The LHCf Collaboration has completed the first step of its scheduled physics program for the study of emission of neutral particles in the forward region of proton-proton (pp) interactions at LHC. Between 2009 and 2010 the LHCf experiment has successfully taken data at 900 GeV and 7 TeV total energy in the center-of-mass frame of reference (CM). After a short presentation of the experimental apparatus, the results for the γ-ray spectrum at $\sqrt{s} = 7\,\text{TeV}$ are presented in this paper.

PACS 13.85.-t – Hadron-induced high- and super-high-energy interactions (energy $> 10\,\text{GeV}$).
PACS 13.85.Tp – Cosmic-ray interactions.
PACS 95.30.Cq – Elementary particle processes.

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1. – Introduction

The LHCf experiment [1] is mainly conceived to study the pp interaction in the very forward region, item of great importance for the high energy cosmic ray community, especially for all those experiment studying the showers of secondary particles produced in our atmosphere by the primary cosmic rays entering from outside. The interpretation of data collected by the different experiments at energies from the so called "knee" of the cosmic ray spectrum, that appears around 10^{15}–10^{16} eV, up to the highest investigated energies, around 10^{20}–10^{21} eV, are not completely consistent. Differences mainly depend on the techniques that are used to reconstruct the parameters of the primary particles and on the hadronic interaction model which is used to simulate the interaction of the primary cosmic rays with the atmospheric nuclei. The energy flow in atmospheric shower development at these energies is dominated by the fragments that are emitted along the direction of motion of the incoming particles. For this reason it is of extreme importance measuring the cross sections for particle production in the forward region and at very high energy in pp and p-ion collisions. All the interaction models used for cosmic ray simulations are calibrated in the forward region by taking into account the results that were achieved at the Sp$\bar{\text{p}}$S collider at CERN around 1990 by the UA7 Collaboration [2]. This experiment measured the forward production of gamma ray particles in the p$\bar{\text{p}}$ interaction at an equivalent energy around 10^{14} eV in the LAB reference system, almost three orders of magnitude lower than the energy achievable at the LHC accelerator. The LHC energy, 14 TeV in the CM frame, corresponds to 10^{17} eV in the LAB system, a value beyond the knee of the cosmic ray spectrum. Measurements at this energy will introduce a strong constraint to interpretation of experimental results for very high energy cosmic rays.

2. – The apparatus

The LHCf detectors (Arm1 and Arm2 in fig. 1) have been installed on the beam line of the LHC, 140 meters far from the Interaction Point IP1, on both sides of the ATLAS detector. In these locations the beam pipe follows a Y-shaped transition path from a single vacuum tube coming from IP1 into two smaller beam pipes separated

Fig. 1. – Arm1 detector (on the left) and Arm2 detector (on the right).

by a 96 mm gap, thus allowing a direct access for instrumentation to the line of the interaction. These regions, the so called recombination chambers, are surrounded by massive structures made of copper, iron and marble, called TANs. TANs are designed to screen the downstream regions by neutral debris which come from IP1 and cannot be deflected by means of magnetic fields. A free slot in each TAN is obtained from the top of the structure down to the space between the two small beam pipes. This slot is about 9 cm wide, 1 m long and 60 cm high. The LHCf detector occupies the first 30 cm length facing IP1, to reduce at minimum the material interposed between IP1 and the detector (only $1\,X_0$ uniform copper thickness due to the beam pipe inside the recombination chamber). The detectors can be moved up and down from the run position (on the beam line) to the "garage" position, where they are protected from radiation by the TAN material. In case of beam interaction with non-zero crossing angle, the detectors can be operated in a lower position to maximize the accessible kinematic region. Each detector contains two independent sampling and imaging electromagnetic calorimeters made of tungsten as absorber, for a total depth of 44 radiation lengths (corresponding to approximately 1.55 nuclear interaction lengths), and scintillator layers as sensitive material. This configuration allows a clean identification of two neutral particles at the same time. Four position-sensitive x/y layers are placed at different depths to maximize the performance for impact point reconstruction both for electromagnetic and hadronic showers. These layers are different for the two detectors and are made of planes of 1 mm square-section scintillating fibers in the Arm1 detector and of $6.4\,\text{cm} \times 6.4\,\text{cm} \times 0.285\,\text{mm}$ single-face silicon microstrip sensors, with $80\,\mu$m implantation pitch and $160\,\mu$m readout pitch, in the Arm2 detector. The use of these two different tracking systems determines a difference in the geometry of the detectors, essentially due to the limited available space. Finally, in front of the detectors, two additional systems made of scintillators are used to monitor the quality of the beam and to study the luminosity of the LHC machine by the Van der Meer scan method.

3. – Data taking

LHCf started data taking since the first physics run of the LHC in 2009, for pp interactions at $450\,\text{GeV} + 450\,\text{GeV}$ beam energies. The total amount of data collected in this phase, from 15th December 2009 until 2nd May 2010, considering both the detectors, consists of 42 hours data taking, corresponding to approximately 10^5 single neutral particle showers. Data were taken for different detector settings, for the study of the systematics, and different vertical positions, to cover all possible kinematic region allowed by the hardware configuration. A longer data taking, of approximately 150 hours, was completed between 30th May and 19th July 2010 for pp interactions at $3.5\,\text{TeV} + 3.5\,\text{TeV}$ beam energies. About 4×10^8 showers were registered in total, including 10^6 double shower events due to the decay of neutral pions. After completing the physics program at $\sqrt{s} = 7\,\text{TeV}$ in July 2010, detectors were removed from the LHC tunnel and exposed to particle beams at the SPS accelerator at CERN for testing performances and to study their slow recovery after heavy irradiation.

4. – Data analysis

A reduced data set has been selected for the first analysis that is shortly described in this article and published elsewhere together with a detailed description of the methods [3]. The best running conditions, corresponding to high beam intensity and very

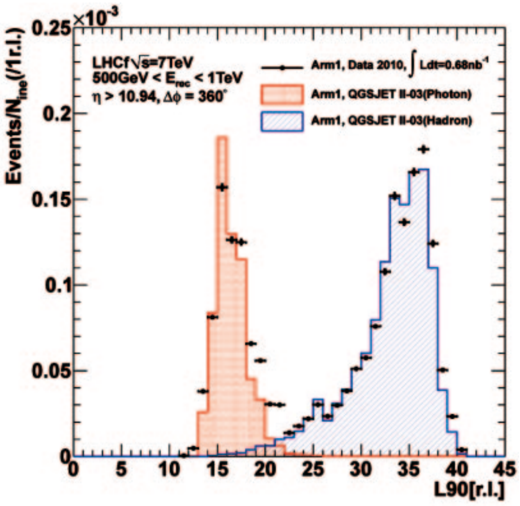

Fig. 2. – Distribution of the L90% variable (described in the text).

low luminosity, were requested for this analysis in such a way to minimize the beam-gas background at to have a negligible pile-up effect. Two different pseudo-rapidity regions covered by both the detectors, $8.81 < \eta < 8.99$ and $\eta > 10.94$, have been selected to allow the comparison and the combination of the results. Discrimination between electromagnetic and hadronic showers has been achieved by exploiting the longitudinal segmentation of the calorimeters. In fig. 2 the distribution of the L90% variable, defined

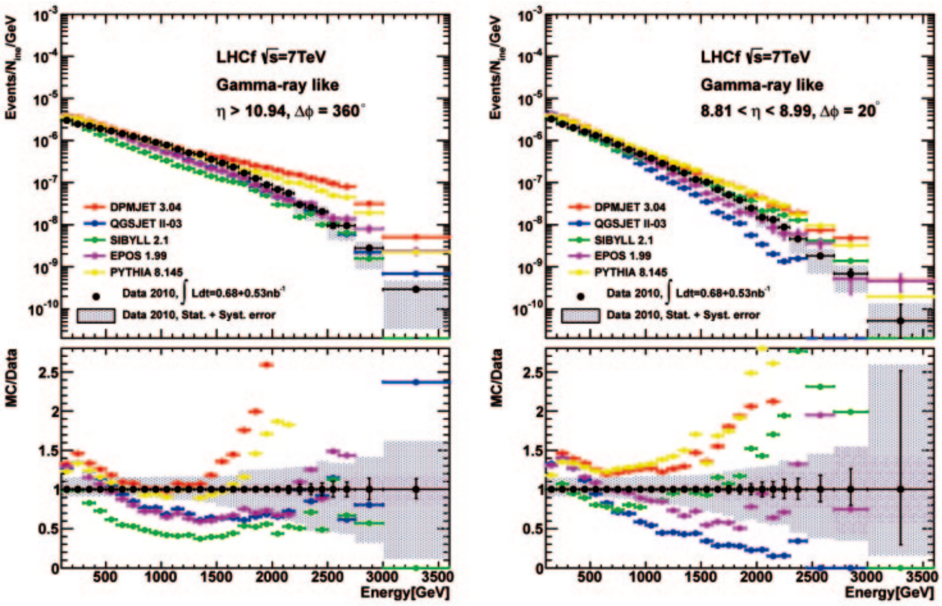

Fig. 3. – Comparison of photon spectra measured by LHCf and predictions of hadronic interaction models.

as the depth along the calorimeter axis at which the 90% of the total released energy has already been deposited, is shown. It is possible to identify a first peak at low values of L90%, due to e.m. showers, and a second peak at higher values, due to hadronic showers. The peak separation improves by selecting smaller ranges of the released energy and the contamination is minimized by defining different cut values at different energies. Nevertheless a not negligible contamination of the unwanted component is not avoidable. A simulation-based method for the estimation of the background is therefore applied to the data samples, allowing to subtract the contribution of contaminating events. The measured spectra for the photon component in the two pseudo-rapidity regions defined above are shown in fig. 3. In the lower graphs the ratio between models and data are shown. As a result none of the models is able to reproduce real data in all the considered energy range and, most markedly, above 2 TeV (for further details see [3]). The LHCf data give therefore an important information to improve the calibration of these models.

5. – Conclusions

The LHCf experiment has completed the first step of its physics programs and has begun to produce important results for the forward physics at LHC. Measured photon spectra in two different pseudo-rapidity regions confirm that all hadronic interaction model must be reviewed to reproduce the experimental data. New results will be available soon after the analysis of all the data that have been collected.

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