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The LHCf experiment: Forward particles production spectra at LHC

E. Berti(1)(2)(*), O. Adriani(1)(2), L. Bonechi(1), M. Bongi(1)(2), G. Castellini(1)(3), R. D'Alessandro(1)(2), M. Haguenauer(4), Y. Itow(5)(6), Y. Iwata(7), K. Kasahara(7), Y. Makino(5), K. Masuda(5), E. Matsubayashi(5), H. Menjo(8), Y. Muraki(5), P. Papini(1), S. Ricciarini(1)(3), T. Sako(5)(6), T. Suzuki(7), T. Tamura(10), A. Tiberio(1)(2), S. Torii(7), A. Tricomi(11)(12), W. C. Turner(13), M. Ueno(5), Q. D. Zhou(5)

(1) *INFN Section of Florence - Florence, Italy*
(2) *University of Florence - Florence, Italy*
(3) *IFAC-CNR - Florence, Italy*
(4) *Ecole-Polytechnique - Palaiseau, France*
(5) *Institute for Space-Earth Environmental Research - Furo-cho, Chikusa-ku, Nagoya, Japan*
(6) *Kobayashi-Maskawa Institute for the Origin of Particles and the Universe, Nagoya University - Nagoya, Japan*
(7) *RISE, Waseda University - Shinjuku, Tokyo, Japan*
(8) *Graduate School of Science, Nagoya University - Nagoya, Japan*
(9) *CERN - Geneva, Switzerland*
(10) *Kanagawa University - Kanagawa, Japan*
(11) *INFN Section of Catania - Catania, Italy*
(12) *University of Catania - Catania, Italy*
(13) *LBNL - Berkeley, CA, USA*

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Summary. — The LHC forward (LHCf) experiment consists of two small sampling calorimeters installed in the LHC tunnel at ±140 from IP1, so that it can detect neutral particles produced by p-ion collisions in the very forward region (pseudo-rapidity $\eta > 8.4$). The main aim of LHCf is to provide precise measurements of the particles produced in high-energy p-p and p-Pb collisions in order to tune hadronic interaction models used by ground-based cosmic rays experiments. In this paper we will discuss the present status of the LHCf experiment, the collected data and measurements done, as well as future prospects.

(*) E-mail: eugenio.berti@fi.infn.it

1. – Introduction

Measurements of flux and composition of the cosmic rays up to the Greisen-Zatsepin-Kuzmin cut-off (GZK cut-off) are necessary to investigate the processes responsible for their acceleration and propagation in the universe. Ultra High Energy Cosmic Rays (UHECRs) can be studied only by ground-based experiments through the indirect detection of the extensive air showers (EASs) they form when interacting with the atmosphere. The reconstruction of the properties of the primary particle is then performed making use of MC simulations. Because EASs physics is described by soft (non-perturbative) QCD, several phenomenological models can be used for this purpose. The lack of experimental calibration data at high energies results in very different predictions among them, strongly contributing to the systematic uncertainty on ground-based cosmic rays measurements. The main purpose of the LHC forward (LHCf) experiment is to provide important information for the calibration of hadronic interaction models at an energy not so distant from the one of UHECRs.

2. – The experiment

LHCf [1] consists of two small sampling calorimeters installed in the Large Hadron Collider (LHC) tunnel at ± 140 m from IP1 (ATLAS interaction point). Being placed after the D1 dipole magnet, only neutral particles produced by p-ion collisions and having pseudo-rapidity $\eta > 8.4$ can reach the experiment. Each one of the two detectors, called Arm1 and Arm2, is made up by two square towers of 22 W and 16 GSO(1) layers for a total length of 21 cm, equivalent to 44 X_0 and 1.6 λ_I. Towers size is 20 mm $\times$ 20 mm and 40 mm $\times$ 40 mm for Arm1, 25 mm $\times$ 25 mm and 32 mm $\times$ 32 mm for Arm2. Energy resolution is better than 5% for γ and about 40% for hadrons. The transverse position of the incident particle is reconstructed using 4 xy imaging layers inserted at different depths. They are formed by 1 mm width GSO-bars(2) in the case of Arm1 and by 160 μm read-out pitch silicon microstrip detectors in the case of Arm2. Position resolution is better than 200 μm for γ and 1 mm for hadrons. More detailed descriptions of the detector are reported elsewhere [2, 3].

3. – Analysis results

Because LHCf requires low luminosity and high β^*, so far data have been acquired during special runs: in 2009–2010 p-p collisions at $\sqrt{s} = 0.9$ and 7 TeV, in 2013 p-p at $\sqrt{s} = 2.56$ TeV and p-Pb at $\sqrt{s_{NN}} = 5.02$ TeV, in 2015 p-p at $\sqrt{s} = 13$ TeV. Although the analysis of this last data set is still ongoing, LHCf has already published some important results relative to γ's, π^0's and neutrons produced in the forward region.

Among different properties that can be investigated by the experiment, forward production spectra are the main analysis objective of LHCf. The two important parameters in the development of EASs related to the forward region are the hardness of the energy spectra and indirectly the *inelasticity* k, defined in such a way that $1 - k$ is the fraction of the energy of the primary particle carried out by the forward leading baryon. These measurements can be performed at an energy very near to the one of the UHECRs, because $\sqrt{s} = 13$ TeV in p-p collisions are equivalent to about 9×10^{16} eV in the reference

(1) Plastic scintillator before 2014 upgrade.
(2) Scintillating fibers before 2014 upgrade.

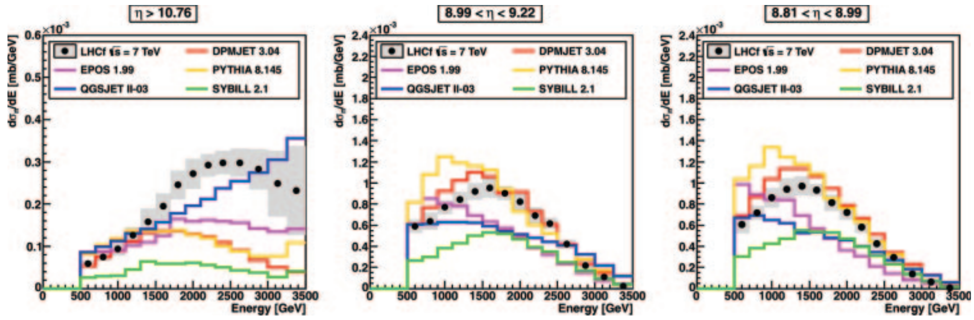

Fig. 1. – Neutron production spectra: comparison of the LHCf results with model predictions in different pseudo-rapidity regions. The black markers and gray shaded areas show the Arm1-Arm2 combined measurements and their systematic errors, respectively [6].

system where the target is at rest. No model reproduces well the experimental data in all the regions considered in the analysis of γ's [4], π^0s [5] and neutrons [6]. In particular, in this last case the deviation observed in the region $\eta > 10.76$ is very strong: this is shown in fig. 1, where we can see the energy spectra of neutrons produced by p-p collisions at $\sqrt{s} = 7\,\text{TeV}$ after Bayesian unfolding [7]. The high energy neutrons production rate observed by LHCf —and only partially reproduced by the QGSJet II-03 model [8]— implies that inelasticity in the region $\eta > 10.76$ is much lower than the one predicted by most models.

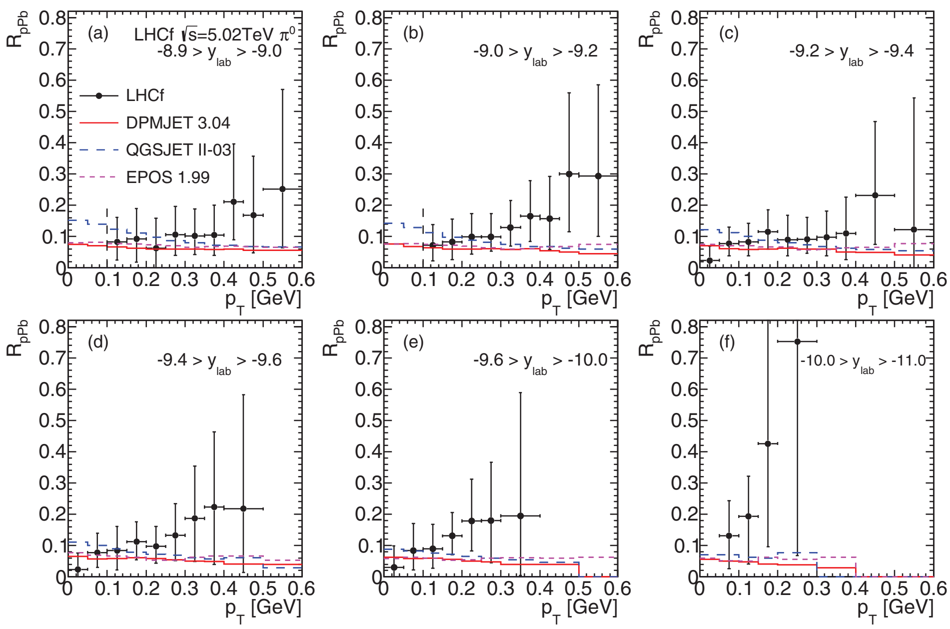

Fig. 2. – Nuclear modification factor for π^0's. Filled circles are LHCf measurements with the error bars incorporating both statistical and systematic uncertainties. Other lines are the predictions by hadronic interaction models [11].

A part from production spectra, there are two other points investigated by LHCf that can provide important information for cosmic rays physics. The first one is the test of scaling laws ($\langle p_T \rangle$ scaling [9], Feynman scaling [10]) that allows us to extrapolate the spectra measured at LHC to higher energies. The second one is the change in the production spectra due to the number of nucleons of the target that can be studied using p-Pb collisions. π^0's, reconstructed from their decays in two γ's, are the best probe to investigate these points, being LHCf detector optimized for electromagnetic showers. Figure 2 shows the nuclear modification factor —defined as the ratio of the π^0 inclusive production cross section for p-Pb at $\sqrt{s_{NN}} = 5.02\,\text{TeV}$ to the same quantity extrapolated for p-p at $\sqrt{s} = 5.02\,\text{TeV}$— as a function of p_T and y_{lab} [11]. Given the large uncertainties, all models are in good agreement with LHCf data, predicting a strong suppression of the production rate in the case the target nucleus is Pb.

4. – Conclusions and future prospects

The LHCf experiment showed that in the forward region no model is perfectly reproducing experimental observations. Measurements of energy and p_T spectra of the neutral particles produced in the very forward region can therefore be used to tune these models. New results at higher energies are expected from the ongoing analysis of the data relative to p-p collisions at $\sqrt{s} = 13\,\text{TeV}$. In addition, this last data set was acquired using a common trigger with the ATLAS experiment, so that we can combine the information of both detectors to identify different kinds of events, *e.g.* diffractive and non diffractive. A new special run at LHC is scheduled using p-Pb collisions at $\sqrt{s_{NN}} = 8.1\,\text{TeV}$ in the end of 2016. Moreover, at the beginning of 2017 LHCf will acquire data from $\sqrt{s} = 510\,\text{GeV}$ polarized p-p collisions at the Relativistic Heavy Ion Collider (RHIC) [12].

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