Status of LHCf

Oscar Adriani, on behalf of the LHCf Collaboration
Dipartimento di Fisica e Astronomia dell'Università di Firenze
INFN Sezione di Firenze
I-50019 Sesto Fiorentino (Fi), ITALY

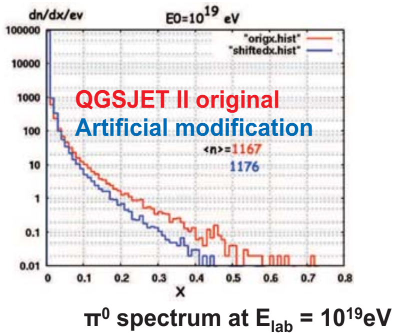
1 Introduction

The LHCf experiment has been designed to precisely measure γ and π^0 spectra produced in the very forward region of the proton-proton collisions at LHC, up to an energy of 14 TeV in the center of mass system. These measurements could significantly improve the correctness of the Monte Carlo models widely used in the high energy cosmic rays (HECR) field, since they allow an experimental data based calibration up to an equivalent laboratory energy of the order of 10^{17} eV. The LHCf experiment has taken data starting from 2008, both at 900 GeV and 7 TeV center of mass energies. It has later on been removed, when the LHC luminosity increased above $10^{30}\text{cm}^{-2}\text{s}^{-1}$. In this paper we report on the first γ inclusive spectrum that have been measured by LHCf; the comparison of this spectrum with the models expectations show significant discrepancies, mainly in the high energy region.

2 Some hints about the expected LHCf physics contribution

A detailed description of the LHCf experiment and of the expected physics performances can be found in [1, 2, 3]. Here we would simply give some hints to point out the important contribution that LHCf can provide to the HECR field.

The most widely used Monte Carlo models describing the hadronic interactions (like for example QGSJET I and II [4], DPMJET3 [5], EPOS [6] and SIBYLL [7]) can be used to derive the expected γ and π^0 spectra for a certain p-p center or mass (or laboratory equivalent) energy. The expectations of the various models differ significantly each other, mainly in the high energy part of the spectra, as can be observed in [2], and can be directly probed by the experimental LHCf measurements. To understand which are the implications of these differences in the HECR field, we have artificially modified the QGSJET II model to produce a π^0 spectrum that differs from the original one by an amount similar to the differences expected between the different models. The artificially modified spectrum, compared with the original one, can be seen in Figure 1, for an equivalent laboratory energy of 10^{19} eV. The spectrum is plotted as function of the $x = E_{\pi^0}/E_{beam}$ variable.



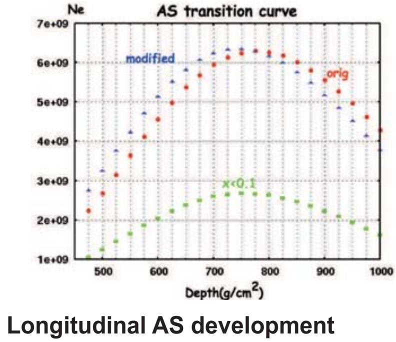


Figure 1: Comparison of the π^0 spectra expected at 10^{19} eV equivalent energy for the original QGSJET II model (red line) and for the artificially modified one (blue line), as described in the text.

Figure 2: Average longitudinal development of the atmospheric shower in the original QGSJET II model (red points) and in the artificially modified model (blue points).

Figure 2 shows the average longitudinal development of the atmospheric shower in the original QGSJET II model (red points) and in the artificially modified model (blue points). A difference in the position of the shower maximum of the order of 30 g/cm^2 is observed. The green points represent the air shower component due to the particles with small Feynman x_F ($x_F < 0.1$), suggesting the fact that the large x_F particles, that can be experimentally measured by LHCf, are the dominant ones for the air shower development. This shift is particularly important since the average position of the maximum of the shower ($< \mathrm{X}_{\max} >$ is one of the 'golden variables' used by the HECR experiments to infer the cosmic rays composition. As an example, Figure 3 [8] shows the Auger measurement for the $< \mathrm{X}_{\max} >$ variable as function of the energy, compared with the models predictions for a light cosmic ray component (proton, red lines) and a heavy cosmic ray component (Iron, blue lines). The yellow rectangle correspond to the 30 g/cm^2 shift, obtained in Figure 2. We can observe that this shift could change in a significant way the interpretation of the experimental data, reinforcing the importance of the direct LHCf measurements of the γ and π^0 spectra in the LHC forward region.

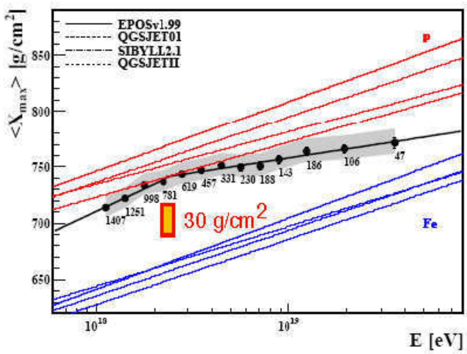


Figure 3: Experimental Auger measurement for the $< X_{\max} >$ variable (black points) compared with the models expectations for a light or heavy cosmic ray composition. The yellow rectangle correspond to the 30 g/cm^2 shift, obtained in Figure 2.

3 The LHCf data taking periods

The LHCf experiment is composed by two independent position sensitive electromagnetic calorimeters, located on both side of the ATLAS experiment, 140 m away from the IP1 LHC collision points. Each calorimeter has a two towers structure, with the smaller tower located at $0°$, approximately covering the region with $\eta > 10$ and the larger one, approximately covering the region with $10 > \eta > 8.4$. The two towers structure allows to reconstruct the π^0 decaying in two γ, hitting separately the two towers, hence providing a very precise absolute energy calibration of the detectors.

Both Arms of LHCf have been installed in 2008 in the LHC tunnel, and they have taken data at 900 GeV and 7 TeV operation. In particular, we have written on disk more than 10^5 events at 900 GeV and more than 3.10^8 events at 7 TeV, allowing a precise measurement of the γ and π^0 spectra forward produced up to the maximum accelerator energies. The detectors have been removed from the LHC tunnel during summer 2010, when the luminosity raised above 10^{30}cm^{-2}s^{-1}, to avoid significant radiation damage. We plan to be reinstalled in the tunnel for the 14 TeV center of mass run, currently foreseen for 2014, after an upgrade of the calorimeters plastic scintillator, to significantly improve their radiation hardness.

4 The single γ analysis at 7 TeV

In this paper we report on the first physics measurement that has been recently published by LHCf [9]: the measurement of the spectrum of single γ very forward produced at 7 TeV center of mass collision energy. The data sample used for this analysis is a small subset of the totally gathered data, corresponding to an integrated luminosity of 0.68 nb^{-1} for Arm1 and 0.52 nb^{-1} for Arm2. The data taking period has been chosen in a particularly clean and low luminosity fill, to minimize backgrounds, hence reducing the systematics of our measurement.

A detailed description of the analysis procedure can be found in [9]. Here we would like to report only on the background conditions and on the measured spectra.

4.1 Backgrounds

There are 3 main sources of background in our single photon spectra analysis:

1. the pileup of collisions in one beam crossing. This is reduced to a negligible level by properly selecting a low luminosity fill ($L < 6 \times 10^{28}\text{cm}^{-2}\text{s}^{-1}$). Given the total inelastic p-p cross section at 7 TeV (σ = 71.5mb) and the bunch structure in the machine for the data taking period (3+3 interacting bunches), we estimated that the background in the LHCf sensitive area is less than 0.2%;

2. background particles produced by the interactions of the primary p-p produced particles with the beam pipe and the structures surrounding the beam pipe (e.g. magnets). The expected backgrounds is mainly composed by low energy particles, as can be inferred from Figure 4, where the background flux is compared with the primary p-p produced particles. We can observe that the contribution becomes negligible ($< 1\%$) above 100 GeV, that is anyway the limiting energy of our trigger system;

3. background particles produced by the beam gas interactions. This background can be directly inferred from the data, by looking at the non-interacting bunches present in the machine. The spectrum due to the beam gas interactions is reported in Figure 5, demonstrating that the beam gas contribution is at least 3 orders of magnitude smaller that the p-p produced particles in the overall energy region from 100 GeV up to 3.5 TeV.

4.2 The single γ measured spectrum

The single γ spectrum measured by LHCf in two different rapidity regions (covered by the small and large towers) is presented in Figure 6, from [9]. The measured spectrum is compared with the predictions from the various models currently used

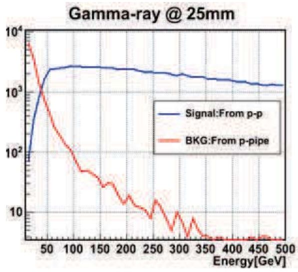


Figure 4: Background expected from the interactions of the primary particles with the beam pipe.

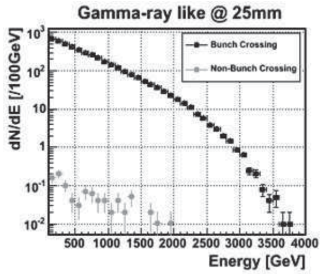


Figure 5: Beam gas related background measured by LHCf.

in the HECR field. As a general comment, we can state that all the models fail to reproduce the experimental data in the overall energy region, from 100 GeV up to 3.5 TeV, even when considering a safe estimation of the experimental systematic errors.

We are currently in contact with the various model developers, to help them to improve the reliability of their Monte Carlo codes, trying to reduce the systematic errors that are present in the HECR experimental analysis.

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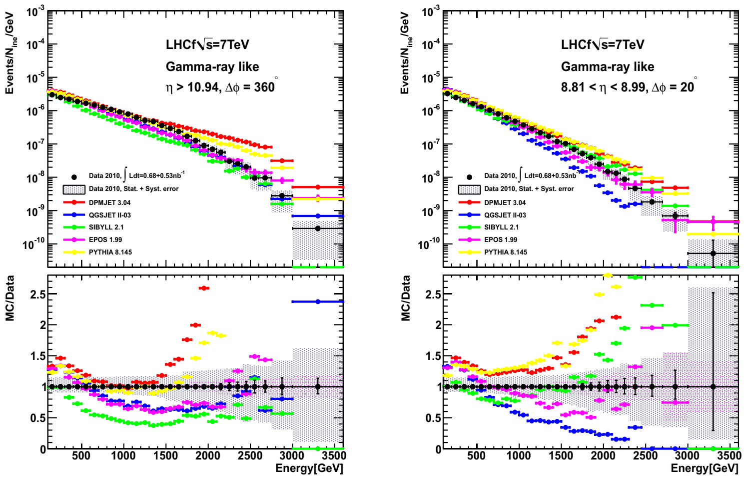

Figure 6: Comparison of the single photon energy spectra between the experimental data and the MC predictions. Different colors show the results from experimental data (black), QGSJET II-03 (blue), DPMJET 3.04 (red), SIBYLL 2.1 (green), EPOS 1.99 (magenta) and PYTHIA 8.145 (yellow). Error bars and gray shaded areas in each plot indicate the experimental statistical and the systematic errors, respectively. The blue shaded area indicates the statistical error of the MC data. Figure from [9].