

LHCf: a LHC Detector for Cosmic Ray Physics

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Abstract

The LHCf experiment has been designed to measure the very forward production of photons and neutral hadrons produced in proton-proton interaction at LHC. These measurements are of essential importance to calibrate the nuclear interaction models used in the Monte Carlo code of air showers, which are used to extract the energy spectra of incoming cosmic rays. Thanks to the unprecedented energy of LHC, LHCf will provide a calibration of nuclear interaction models with real data up to energies relevant to test the most debated region of the cosmic ray energy spectra.

1 Introduction

One of the most debated question in cosmic ray physics is related to the existence of events above the so called GZK cut-off. The existence of these events, if confirmed, poses some intriguing questions to our understanding of astroparticle physics and, eventually, asks for New Physics in order to explain such a production. Indeed, evidence of Ultra High Energy Cosmic Rays, above the GZK cut-off, has been reported for the first time by the AGASA experiment [1]. On the contrary, the results of the HiRes [2] experiment are consistent with the existence of the cut-off. Recently the AUGER Collaboration [3, 4] reported results consistent with the HiRes ones. A key point which raises observing the cosmic ray energy spectra (Fig. 1) is the importance of the energy scale calibration between different experiments. It has been noted that with a shift by about 20% in the energy scale the disagreement between AGASA and HiRes results almost disappears. Indeed, many of the experimental procedures used to derive the energy spectra of the incoming cosmic rays depend strongly on the nuclear interaction models used in the Monte Carlo codes of the air showers, which amounts for the the main source of systematic uncertainties.

The derivation of the energy spectra is not the only item in cosmic ray physics in which we need to rely on Monte Carlo assumptions. Another open issue is the chemical composition of cosmic rays. Cosmic rays are not purely protons but they contain also heavy nuclei. Nuclear cascade showers initiated by the disintegration of heavy nuclei develop more rapidly in comparison with the showers initiated by protons. Fig. 2 shows the distribution of the shower maximum, X_{MAX} , as obtained by different collaborations around the knee region (10^{16} eV), compared with several different Monte Carlo models [5]. The position of the shower maximum clearly depends on the composition of the cosmic rays. As can be seen from the same Figure, different models predict different composition. Not being sure on which nuclear interaction model one should use, effectively reduces our ability to identify correctly the primary nucleon.

The importance of a correct choice of the nuclear interaction model is hence mandatory for a detailed study of cosmic ray physics. For this reason a detailed calibration of Monte Carlo codes

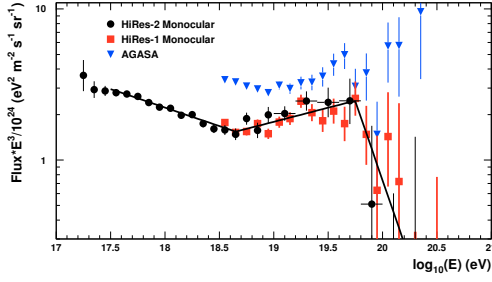


Fig. 1: Energy spectra of cosmic rays at the highest energies. Blue triangles represent the AGASA data, while red and black marks represent the new results from HiRes [2]. A clear discrepancy between AGASA and HiRes can be seen in the region above 10^{20} eV.

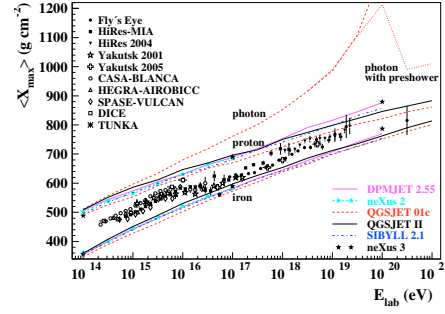


Fig. 2: The position of the shower maximum X_{MAX} is shown as a function of the primary cosmic ray energy. The various lines correspond to predictions made by different Monte Carlo models. Plot from Ref. [5]

with real data is clearly of extreme importance. In order to calibrate these codes and choose between different models it is very important to have a precise knowledge of the energy spectrum of forward emitted particles which are the main perpetrators of the air shower development. LHC with its unprecedented energy of 14 TeV in the center of mass system (equivalent to about 10^{17} eV in the laboratory system), gives us a unique opportunity to perform a complete calibration of Monte Carlo models in an energy range relevant to explore the already mentioned open questions of cosmic ray Physics.

The LHCf experiment [6] has been designed in order to measure the forward production spectra of photons and π^0 's and the leading particle spectrum, thus providing all the essential tools needed to perform a detailed nuclear interaction model calibration.

2 The LHCf experiment

The main purpose of the LHCf experiment is to measure the neutral particle production in the very forward region at LHC: it should be able to identify photons, π^0 and neutrons, measure their energy spectra (> 100 GeV) down to the high rapidity region and reconstruct the π^0 invariant mass thanks to the accurate measurement of the shower position and energy. In order to be compliant with these goals a double arm calorimeter design has been chosen. The two detectors are located on both side of the Interaction Point 1 (± 140 m) at the Large Hadron Collider (LHC), at CERN. The two calorimeters are housed in a beam absorbing structure (TAN) in which the two proton beams are steered in the two separate beam lines which circulate in the LHC machine. Thus the flux of charged particles is swept away and only the neutral ones reach the calorimeter surface.

Each detector is a small sampling electromagnetic calorimeter arranged in a double tower geometry, each tower being made of plastic scintillators (16 layers) interleaved with tungsten layers as absorber (22 layers) and four layers of position sensitive detectors. The total dimensions of each detector (29 cm length, 9 cm width and 60 cm height) is constrained by the available slot in the

TAN region. The two detectors are very similar but not identical: the geometrical arrangement of the two towers is different and they also differ for the position sensitive layers. In detector #1 (ARM1) four layers of X-Y hodoscopes made with array of $1\text{ mm} \times 1\text{ mm}$ scintillation fibers (SciFi) provide transverse position information of the showers. The position resolution for the shower center is expected to be $200\text{ }\mu\text{m}$. A schematic of Detector #1 is shown in Fig. 3.

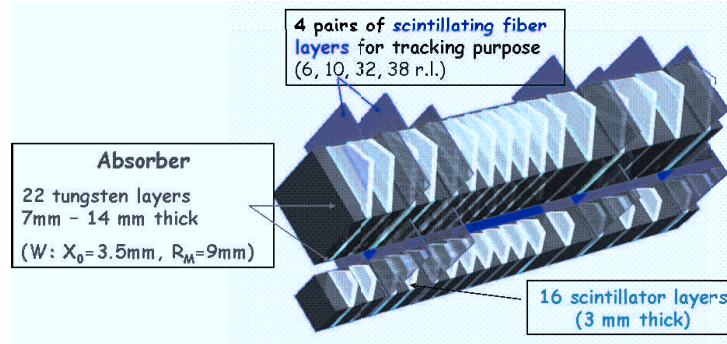


Fig. 3: A schematic drawing of the ARM1 LHCf calorimeter. The two towers have transverse dimensions of $2 \times 2\text{ cm}^2$ and $4 \times 4\text{ cm}^2$. The scintillator tiles are read out with phototubes. Four layers of scintillation fibers are used for tracking purpose.

The structure of Detector #2 (ARM2) is the same, but the two towers are stacked on their edges with an horizontal offset in order to maximize the effective aperture and the position sensitive layers are replaced by silicon microstrip detectors, as can be seen in Fig. 4. The detector spatial resolution (i.e. the precision on the photon impact point measurement) is shown in Fig. 5 as a function of the depth for several photon energies ranging from 56 GeV to 1800 GeV.

The absorber length of the two calorimeters is enough to accurately measure the photon energy up to 2 TeV. The plastic scintillators provide both fine sampling of shower energy as well as a level 2 online trigger for data taking. Due to the smallness of the tower sizes, which are comparable to the Moliere radius of the electromagnetic showers, there is a certain amount of side leakage. However, this leakage can be corrected for by applying the position measurements of the silicon/scintillating fibre layers. Energy resolution is expected to be $3\% / \sqrt{E(\text{TeV})} + 1.2\%$. Also the capability to reconstruct separately the two showers from the $2\text{ }\gamma$ s from π^0 decays allows for an excellent reconstruction of the invariant mass (5%) and thus provides an invaluable tool to calibrate the absolute energy scale, which is of crucial importance for the Physics program of LHCf (Fig. 6).

Good discrimination of hadron (neutron) showers from electromagnetic (γ) showers can be achieved by measuring the longitudinal shower distribution. Energy resolution of hadron showers is expected to be 30% at 6 TeV due to the longitudinal shower leakage through the back of the calorimeters.

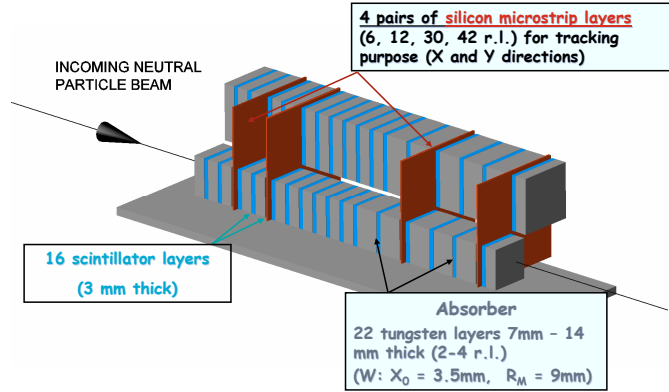


Fig. 4: A schematic drawing of the ARM2 LHCf calorimeter. The two towers have transverse dimensions of $2.5 \times 2.5 \text{ cm}^2$ and $3.2 \times 3.2 \text{ cm}^2$. The scintillator tiles are read out with phototubes while the silicon microstrip detectors have a redout pitch of 160 microns and provide a high precision measurement of the shower profile.

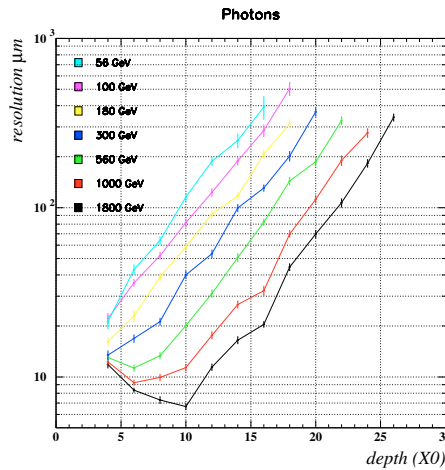


Fig. 5: Spatial resolution as a function of layer depth for the ARM2 calorimeter with silicon modules at various photon energies.

3 Monte Carlo Model Discrimination

The capability of LHCf to disentangle different interaction models is shown in Fig. 7 both for the γ and neutron energy spectra. The models used are DPMJET3 [7], QGSJET-II [8] and SYBILL [9]. Depending on the nuclear interaction model used the energy spectra change more or less significantly. In the case of γ energy spectra, the discriminating power is already significant

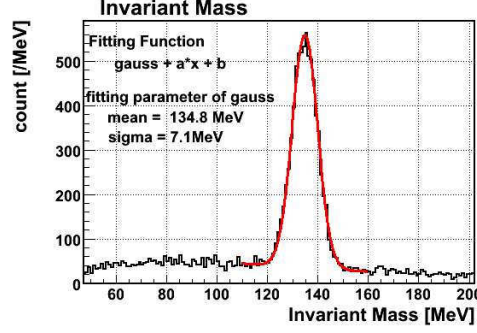


Fig. 6: Invariant mass resolution for π^0 for the ARM1 calorimeter.

at 1 TeV between SYBILL and the other codes, while discrimination between DPMJET3 and QGSJET-II can be achieved through a more sophisticated analysis, as described in Ref. [6]. The neutron sample gives more discrimination between different models. As it is shown in Fig. 7, even with a pessimistic 30% energy resolution, a very good disentangling of the different models is feasible.

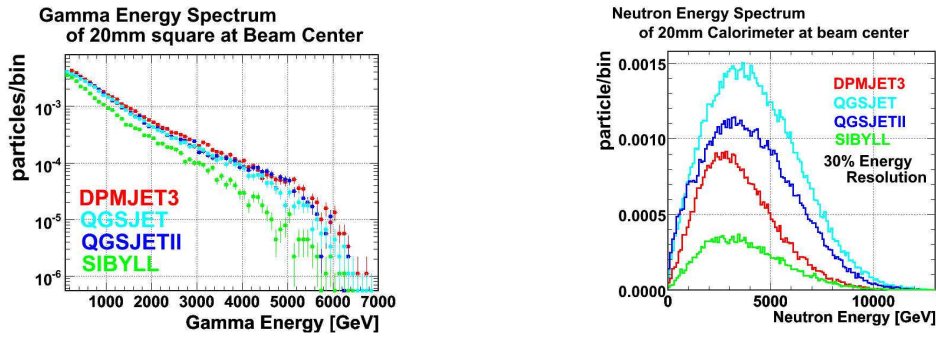


Fig. 7: Expected energy spectrum for γ s and neutrons according to different interaction models. For neutrons a 30% energy resolution has been taken into account.

4 Status of the Experiment and Running scenario

The two LHCf calorimeters are fully assembled already since several months. Both were successfully pre-installed in the TAN region, to test all the connectivity, mechanics, cabling, etc. (Fig. 8) and the experiment is ready for the final installation into the LHC tunnel waiting to take data with LHC beams.

The LHCf detectors will take data in the first running period of LHC, already during the commissioning of the machine (mid 2008) till the LHC luminosity will not exceed $10^{31} \text{ cm}^{-2}\text{s}^{-1}$. Then the detector will be removed for reasons of radiation damage of the scintillator component. A successive phase, in which the detector will be re-installed at the next opportunity of a low luminosity run and during heavy ion runs is under discussion.

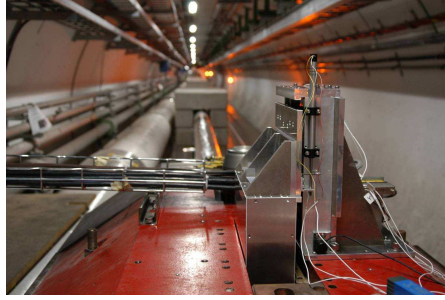


Fig. 8: ARM1 detector pre-installed in the TAN location in the LHC tunnel.

5 Conclusions

The LHCf experiment will take data at LHC in order to calibrate air shower Monte Carlo codes up to the energy of 10^{17} eV, thus providing invaluable input to questions posed since the first detection of UHECR. The two calorimeters are ready to take data and will be installed in the LHC tunnel at the beginning of 2008, while data taking will start at the beginning of LHC beam commissioning.

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