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The LHCf experiment: modelling cosmic rays at LHC

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Abstract. The LHCf experiment at LHC has been designed to provide a calibration of nuclear interaction models used in cosmic ray physics up to energies relevant to test the region between the knee and the GZK cut-off. Details of the detector and its performances are discussed.

1. Introduction

The derivation of both the cosmic ray energy spectra as well as of the chemical composition of cosmic rays are just two examples of key measurements in cosmic ray physics for which we need to rely largely on Monte Carlo assumptions. The importance of a detailded calibration of the Monte Carlo nuclear interaction model with real data is hence mandatory for a detailed study of cosmic ray physics. 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. So far, the only high energy data set available to calibrate the different models, are the ones provided by the CERN UA7 collaboration [1] up to an energy of 10^{14} eV, well below the interesting region for HECR events. An important improvement can be achieved at LHC. In fact, the laboratory equivalent energy of LHC is 10^{17} eV, hence Monte Carlo models can be calibrated at LHC up to energies relevant to explore the region between the knee and the GZK cut-off. The LHCf experiment [2] 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 such calibration.

2. The LHCf Detector: layout and performances

The LHCf detector consists of a double arm sampling electromagnetic calorimeter. The two calorimeters are 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 two calorimeter are very similar however they differ both for the geometrical arrangment of the two towers as well as for the position sensitive layers. One of the two arm (ARM1), uses X-Y hodoscopes made with array of scintillating fibers (1 mm $\times$ 1 mm) to provide information on the transverse position of the shower. A position resolution for the shower center of about 200 μm is expected. The other detector (ARM2), instead, makes use of silicon microstrip detectors as position sensitive layers. This ensures an even better position resolution (few tenth of μm), as can be seen in Fig. 1.

The total dimensions of each detector is quite small (29 cm length, 9 cm width and 60 cm height) and is constrained by the available slot in the region where the detectors are located. The two detectors, in fact, are located on both side of the Interaction Point 1 ($\pm$ 140 m) at the Large Hadron Collider (LHC) and 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.

The double arm–double tower design has been chosen in order to be compliant with the LHCf main physics goals. Indeed, the main purpose of the 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.

Detailed simulation as well as results from beam test have been used to evaluate the detector performances. Energy resolution is expected to be $3\%/\sqrt{E(TeV)} + 1.2\%$. Also the capability to reconstruct separately the two showers from the 2 γs from π^0 decays has been evaluated. It allows for an excellent reconstruction of the invariant mass (5%) and thus provide an unvaluable tool to calibrate the absolute energy scale, which is of crucial importance for the physics program of LHCf (Fig. 2).

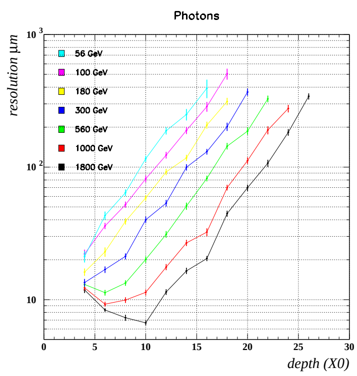

Figure 1. Spatial resolution as a function of layer depth for the ARM2 calorimeter with silicon modules at various photon energies.

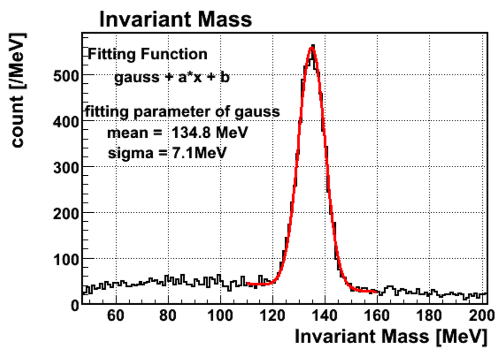

Figure 2. Invariant mass resolution for π^0 for the ARM1 calorimeter.

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 out the back of the calorimeters.

The capability of LHCf to discriminate between different interaction models is shown in Fig. 3 both for for the γ and neutron energy spectra. The models used are DPMJET3 [3], QGSJETII [4] and SYBILL [5]. As can be seen from the Figure, significant variations are expected in the energy spectra according to the nuclear interaction model used. In the case of γ energy spectra, the discriminating power is already significant at 1 TeV between SYBILL and the other codes, while discrimination between DPMJET3 and QGSJETII can be achieved through a more sophisticated analysis, as described in Ref. [2].
The neutron sample gives more discrimination between different models. As it is shown in Fig. 3, even with a pessimistic 30% energy resolution, a very good disentangling of the different models is feasible.

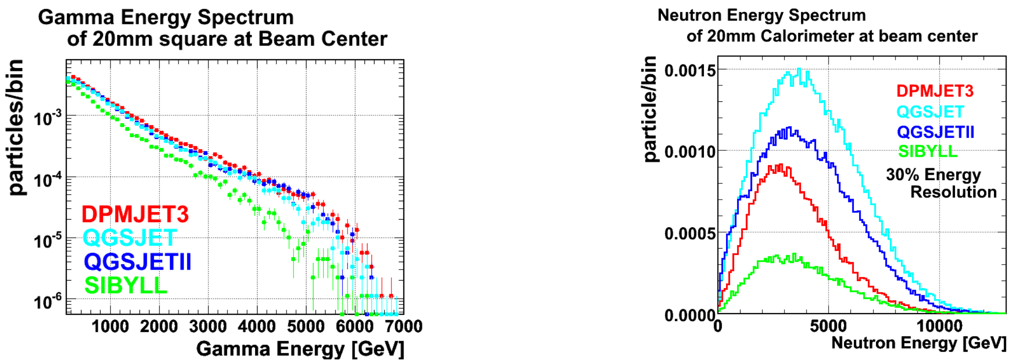

Figure 3. Expected energy spectrum for γs (left) and neutrons (right) according to different interaction models. For neutrons a 30% energy resolution has been taken into account.

3. Running plans and conclusions

The two detectors have been fully assembled and tested. They have been also pre-installed in the TAN region to check all the connectivity, mechanics, cabling, etc. and the experiment is now ready for the final installation into the LHC tunnel in the beginning of 2008.

The LHCf detectors will take data in the first running period of LHC, already during the commissioning phase of the machine (mid 2008) till the LHC luminosity will not exceed 10^{31} cm^{-2}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.

The LHCf experiment will 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.

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