Università degli studi di Firenze

Measurement of the energy spectra of neutrons produced in the very forward region at LHC $\sqrt{s}$=13 TeV p-p collisions

Supervisor
Prof. Oscar Adriani

PhD Student
Eugenio Berti

In order to have a better understanding of the processes responsible for acceleration and propagation of cosmic rays in the universe, it is necessary to perform measurements of flux and composition up to the GZK cutoff region. Because the flux of ultra high energy cosmic rays (UHECRs) - i.e. cosmic rays having energies above 10^{18} eV - is less than 1 particle per km^2 per year, it is possible to study them only using large area detector arrays at the ground level. In this case their properties are obtained indirectly from the reconstruction of the extensive air showers (EASs) they form when interacting with the atmosphere. EASs physics is described by soft (non perturbative) QCD, based on some phenomenological models. Due to the lack of experimental calibration data at high energies, models exhibit very different prediction among them. This fact is strongly affecting the results of ground-based cosmic rays experiments with large systematic uncertainties.

The main aim of the LHCf (LHC–*forward*) experiment is to provide high energy calibration data that can be useful to test and tune models used in the very forward region. LHC is the most suitable place for this purpose because p-p collisions at $\sqrt{s}$=14 TeV is equivalent to 10^{17} eV in the reference frame in which the target is at rest, an energy very near to the one of UHECRs. In order to do that, LHCf makes use of two small sampling calorimeters installed at ± 140 m from LHC IP1, so that it can detect neutral particles produced by p-p collisions having pseudo-rapidity $\eta > 8.4$. Detectors are made up by two towers of 22 W and 16 GSO layers in which 4 xy imaging planes are inserted at different depths for the reconstruction of the transverse position of the incident particle. Being the available space in the machine very limited, calorimeters are optimized for the reconstruction of electromagnetic showers ($\sigma_E/E < 5\%$), whereas hadronic showers are not completely contained ($\sigma_E/E \sim 40\%$). Because of this reason, the main analysis target of LHCf is the study of the properties of forward π^0s by the detection of the 2γ in which they decay. On the other side, ground-based cosmic rays experiments observed a strong disagreement between the measured and the predicted number of muons at the ground level. This was explained by strong uncertainty in the baryons production rate in the EAS at the beginning of its development. Thus, despite performance is not as good as for the π^0s case, LHCf can provide important information on this problem by the measurement of forward neutrons energy spectra.

In this work we present the results relative to the energy spectra of the forward neutrons produced at LHC $\sqrt{s}$=13 TeV p-p collisions. Because detector was upgraded before this data taking, beam test were performed at the SPS before and after LHC operation. The work is divided in two main parts.

The first part is relative to the calibration of the upgraded detector for the reconstruction of hadronic showers. This was performed both using beam test data and MC simulations. The former were used for the estimation of the gain of each scintillator layers, the latter for position dependent correction factors, deposited energy to primary energy conversion coefficients and more general studies relative to detector performance. In the end, experimental and MC data were compared after applying all reconstruction factors in order to estimate the final uncertainty on the energy scale.

The second part is relative to the analysis of LHC data. Preliminary studies were performed on MC simulations to set the event selection criteria, mainly related to software trigger and particle identification. Neutron energy spectra were then obtained in three different rapidity regions: $\eta > 10.76$, $8.99 < \eta < 9.22$, $8.71 < \eta < 8.99$. Systematic uncertainties due to energy scale, multiple hit contamination, limited position resolution, particle identification and beam position were estimated. Being $\sigma_E/E \sim 40\%$, reconstructed spectra are enough to test interaction models, but can not be used to extract direct information for tuning. In order to provide useful information for model developers, a bayesian unfolding method was used to take into account the limited energy resolution. Finally, neutron energy spectra at $\sqrt{\mathrm{s}}$=13 TeV were compared to the ones obtained at $\sqrt{\mathrm{s}}$=7 TeV.