PROCEEDINGS OF SCIENCE

LHCf Program for Run III

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The LHC-forward (LHCf) experiment has measured the very forward neutral particle production cross section in proton-proton and proton-lead collisions at the LHC up to $\sqrt{s}$ = 13 TeV and $\sqrt{s_{NN}}$ = 8.16 TeV, respectively. The experiment employs two independent detectors placed on opposite sides along the beam line approximately 140 meters away from the interaction point of the ATLAS experiment (IP1). The detectors are able to measure neutral particles with pseudorapidity greater than 8.4, up to zero-degree. These measurements are extremely useful for the calibration of the hadronic interaction models used to simulate the atmospheric showers of secondary particles induced from an high energy cosmic ray. Decreasing the uncertainty between different models it is possible to improve the precision of the high energy cosmic rays measurements.

In this contribution the LHCf physics motivation for the Run III of LHC are discussed. The beam parameters and the expected operation time needed for our minimum physics program are described for both p-p run at 14 TeV and p-O run at 9.9 TeV. Finally, a brief summary of the ongoing upgrade on the Arm2 detector is given.

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1. The LHCf Experiment

The LHC-forward experiment (LHCf) has measured the neutral particles production in the very-forward region since its first operation in 2009. LHCf is made of two independent detectors (Arm1 and Arm2) placed 140 metres away from the Interaction Point 1 (IP1) at zero degree with respect to the colliding beams, on opposite sides [1]. Since charged particles are deflected by the D1 dipole magnet (placed between LHCf and IP1), only neutral particles produced in the collision are able to hit the detector: this particular position allows the experiment to perform the measurements of the production cross section of photons, neutrons and π^0s in a very forward pseudorapidity region ($\eta > 8.4$). Both detectors are composed of two sampling calorimeters. Each calorimeter employs 16 Gd_2SiO_5 (GSO) scintillator layers alternated with tungsten layers. The transverse impact position of the incident particle is measured with GSO bars in Arm1 and silicon micro-strip detectors in Arm2. The LHCf experiment has carried out measurements in proton-proton collisions at $\sqrt{s}$ = 0.9, 2.76, 7 and 13 TeV [2–9], and in proton-lead collisions at $\sqrt{s_{NN}}$ = 5.02 and 8.16 TeV [10] so far.

The measurement of the very forward secondary particles produced in high energy hadronic collisions is strictly correlated with the study of the ultra-high-energy cosmic rays (UHECRs). Since UHECRs can only be measured with ground-based experiments, detailed Monte Carlo simulations of the shower of secondary particles produced by the interaction of the primary cosmic ray with the atmosphere (the so called “air-showers”) must be employed. Most of the energy flow of an air-shower is concentrated in the very-forward region where soft quantum chromodynamics processes dominate, so phenomenological hadronic interaction models must be used in the simulations. The discrepancy between the predictions of different models gives the main contribution to the uncertainty on the measurements of UHECRs spectrum and mass composition. The tuning of hadronic interaction models in the very-forward region with data of accelerator experiments can therefore reduce the systematic uncertainty of UHECRs measurements [11].

The physics motivations and beam requirements for the planned LHC operation at $\sqrt{s}$ = 14 TeV are discussed in Section 2, while the motivations and requirements for the proposed p-O run at $\sqrt{s_{NN}}$ = 9.9 TeV are explained in Section 3. The trigger and hardware upgrades are described in Section 4. Even if the LHCf run is not in the official LHC program yet and the p-O run is not confirmed, the LHCC Research Board has already approved the LHCf technical proposal for Run III [12].

2. Proton-Proton Run at $\sqrt{s}$ = 14 TeV

The proton-proton run at 14 TeV will give the possibility to extend the LHCf measurements up to an equivalent energy of a cosmic ray of 10^{17} eV. Even if significant changes from the physics observed ad 13 TeV are not expected, thanks to the upgrades ongoing on Arm2 detector and trigger logic (as described in Section 4) LHCf will be able to operate at a luminosity 10 times larger than previous run at 13 TeV. As a consequence, the higher statistics expected will improve the statistical uncertainty on the results and will give the possibility to measure also η and K^0 spectra. The comparison between the statistical error of 13 TeV data and the expected one for 14 TeV for π^0 transverse momentum spectra is shown in Figure 1: the increase of statistics improves the precision of the measurements and allows to cover a wider phase space of transverse momentum (P_T) and Feynman-X (X_F). The precision of the expected measurements at 14 TeV is enough to discriminate between different hadronic interaction models in an extended $P_T - X_F$ region.

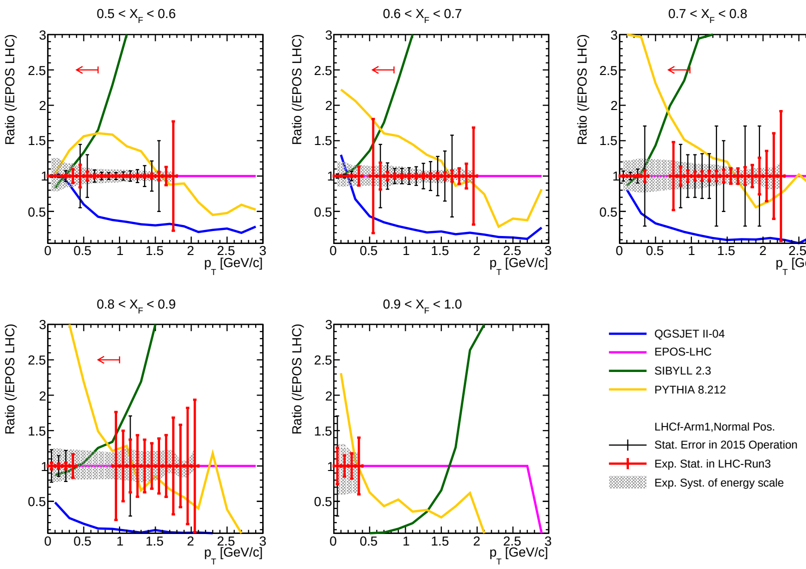

Figure 1: Ratio of the π^0 P_T spectra in different X_F bins predicted by several hadronic interaction models with respect to EPOS-LHC model (coloured lines). Black and red error bars represent the statistical error in 13 TeV data and the one expected for 14 TeV data, respectively. The red small arrow indicates the P_T coverage of 7 TeV results.

The maximum luminosity at which LHCf will be able to operate is $\sim 10^{30}\mathrm{s}^{-1}\mathrm{cm}^{-2}$, with a pile-up parameter (i.e., average number of collisions per bunch crossing) ~ 0.014 and $\beta^* \sim 10$ m. With these beam parameters the minimum physics program (an integrated luminosity of $\sim 20\ \mathrm{nb}^{-1}$) can be completed in ~ 2 days of operation.

3. Proton-Oxygen Run at $\sqrt{s_{NN}} = 9.9$ TeV

A proton-oxygen run would be the optimal configuration to reproduce the collision of a cosmic ray with a light nucleus of the atmosphere, so a measurement of the very-forward production cross section of photons, π^0s and neutrons would be very important for the improvement of the hadronic interaction models. LHCf will potentially operate on the proton-remnant side, with the other side occupied by the ATLAS ZDC.

Another feature of a p-O collision is that the contribution of ultra peripheral collisions (UPC, where the proton interacts with a virtual photon of the electromagnetic field of the nucleus) is much smaller with respect to a p-Pb collision. Since LHCf is not able to discriminate between UPC and QCD collisions, the subtraction of the UPC component (necessary to compare the data with the hadronic interaction models) has to be done relying on simulations [13]: this introduces a systematic uncertainty related to the discrepancy between the different models used to simulate UPCs, which becomes larger as the UPC contribution increases.

In Figure 2 the very-forward photon energy spectra in p-Pb and p-O collisions are compared, separating the QCD contribution from the UPC one. Clearly, the UPC contribution is of the same order of the QCD one in p-Pb collisions while it is roughly two orders of magnitude smaller in p-O collisions. The expected systematic uncertainty associated to the UPC subtraction is estimated to be negligible in p-O with respect to the other sources of systematic errors, while it considerably affects the total uncertainty of p-Pb results.

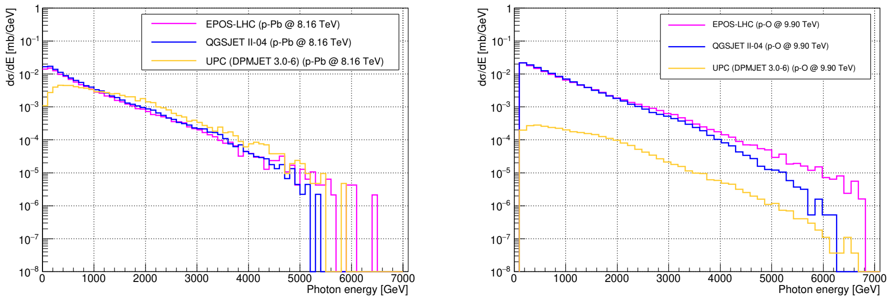

Figure 2: Photon energy spectrum at zero-degree ($\eta > 10.94$) in p-Pb collisions at $\sqrt{s_{NN}} = 8.16$ TeV (left) and p-O collisions at $\sqrt{s_{NN}} = 9.9$ TeV (right). The predictions of EPOS-LHC and QGSJET II-04 hadronic interaction models are shown as magenta and blue histograms, respectively, while the estimated UPC contribution is shown in yellow.

The proposed luminosity for the LHCf p-O run is $\sim 10^{28} \mathrm{s}^{-1} \mathrm{cm}^{-2}$ with a pile-up parameter of ~ 0.01 and $\beta^{*} \sim 10$ m. With these parameters the target integrated luminosity of 0.7 nb^{-1} can be achieved in ~ 2 days.

In principle it is possible to operate in the O-remnant side or in O-O collisions, but the detector has to be moved at least 15 mm away from the zero-degree position due to the higher particle multiplicity.

4. Detector Upgrade

In order to increase the statistics of high energy and π^0 events, a new trigger logic scheme was developed. In addition to the standard "shower trigger" (100% efficiency for photons and 70% efficiency for neutrons, prescaling factor of 14), two new trigger conditions are included: the "type I trigger" dedicated to π^0 events where the two decay photons hits two different calorimeters (98% efficiency, no prescaling factor) and the "high-EM trigger" dedicated to high energy photons (E > 1 TeV) and π^0 events with both decay photons in the same calorimeter (97% efficiency, no prescaling factor).

Since the DAQ of the silicon detectors of Arm2 was the bottleneck that limited the acquisition rate in previous operations, an upgrade of the silicon readout electronics was necessary to achieve the required DAQ rate for the planned operations. The old data transmission links which used FOXIchip protocol has been replaced by a standard optical Gbps Ethernet protocol, which reduces the dead time by a factor 10. The whole readout and control system is being upgraded to replace aged components and to handle the new transmission protocol.

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