LHCf experiment; astrophysics connection of high-energy nucleus collisions

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ABSTRACT Ultrarelativistic nucleus-nucleus collisions take place in the earth's atmosphere, namely cosmic ray air showers. To interpret the air shower observation to the properties of primary particles, the knowledge of the high-energy interaction is indispensable. The Large Hadron Collider forward (LHCf) experiment has measured particle production at η>8.4, where the secondary particles carry a large fraction of collision energy, with the LHC √s=0.9, 2.76, 7 and 13 TeV proton-proton collisions. To study the nuclear effect at an extreme condition, measurements with the $\sqrt{s_{NN}}$=5 TeV p-Pb collisions were also performed. The observed cross sections of π^0 and neutrons, nuclear effect of the π^0 production in p-Pb collisions are so far well explained by the major interaction models used in the cosmic-ray physics. To extend the √s coverage, a new experiment RHICf is in preparation.

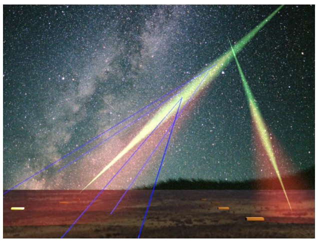

Fig.1 Schematic view of atmospheric air shower

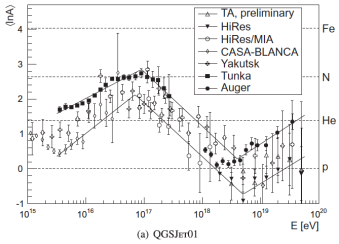

Fig.2 Average mass number <lnA> of the primary cosmic rays as a function of energy complied from air shower data [3].

Introduction to the CR physics

Energy spectrum of cosmic rays is measured up to 10^{20}eV. Because of their low flux, observations are performed through atmospheric air showers (Fig.1). In the analysis of air shower data, we must rely on the Monte Carlo simulation assuming a hadronic interaction model. In the LHC era, hadronic interaction, especially in the non-perturbative domain, is extensively studied using the accelerator data [1]. This paper introduces a dedicate experiment at LHC, *Large Hadron Collider forward (LHCf) [2]*, operated with proton-proton collisions and proton-Lead collisions at LHC.

Because the primary cosmic-ray particles can be heavy nuclei (Fig.2 [3]), and the target atmosphere is light nuclei like Nitrogen and Oxygen, ultimate goal to understand the air shower phenomenon is to understand the Ultrarelativistic Nucleus-Nucleus Collisions.

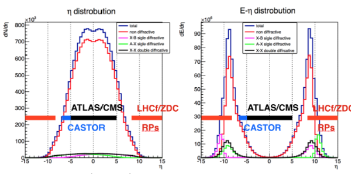

Fig.3 Particle production in 13TeV proton-proton collisions simulated by PYTHIA8

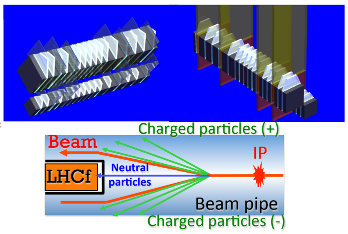

Fig.4 Schematic view of the LHCf Arm1 (top-left) and Arm2 (top-right) detectors Location of the LHCf detector at one side of IP1 (bottom)

LHCf Experiment

In high-energy hadron collisions, most of the particles are produced in the central rapidity while most of the energy is carried by small number of forward particles (Fig.3). LHCf has installed two independent detectors (Arm1 and Arm2, Fig.4) in the ATLAS interaction point (IP1) at LHC to measure the forward particle production. Detectors are installed 140m away from IP1, where only neutral particles (photons and neutrons) can arrive (Fig.4). The detectors are electromagnetic calorimeters with energy and position resolutions <5% and <200um for photons with energy >100GeV [4], and 40% and <1mm for >500GeV hadronic showers [5].

LHCf Results

LHCf took data at LHC with 0.9, 2.76, 7 and 13 TeV proton-proton collisions. Data with 5.02 TeV proton-Lead collisions is also available. Measured cross sections, spectra and nuclear modification factors are compared with various hadronic interaction models and they are compared between different collision energies to test energy scaling.

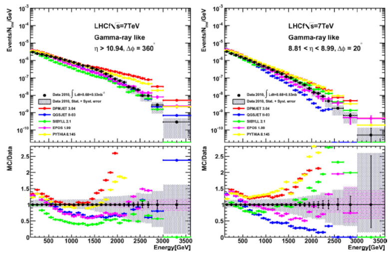

Fig.5 Photon spectra measured at two pseudo-rapidity ranges including zero degree with 7TeV p-p collisions [6]. LHCf result is at the middle in the large model variation.

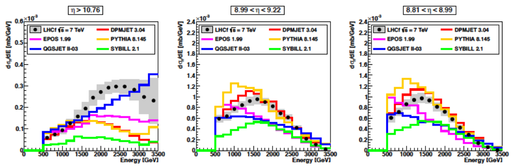

Fig.6 Neutron spectra measured at three pseudo-rapidity ranges including zero degree with 7TeV p-p collisions [7]. High neutron yield around zero degree is qualitatively explained only by the QGSJET II-03 model.

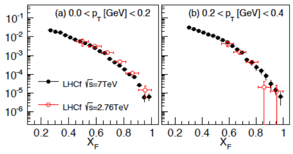

Fig.7 Feynman x_F spectra measured at two p_T ranges with 2.76 and 7TeV p-p collisions [8]. Within the experimental uncertainty, scaling of x_F spectra is found.

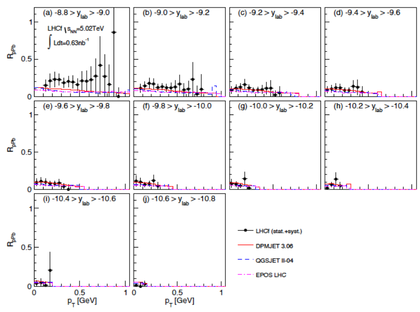

Fig.8 Nuclear modification factors, R_{pPb}, of π^0 production in the proton side of $\sqrt{s_{NN}}$=5.02TeV p-Pb collisions [8]. R_{pPb} is shown as a function of p_T at 10 rapidity ranges. Within the experimental uncertainty, R_{pPb} is explained by the models.

Summary and RHICf

LHCf has so far published photons, neutrons and π^0 production cross sections with the data taken during LHC Run1. Models are now being tuned with care of other measurements.

Further experiments including 1) LHC p-Pb collisions at the highest energy, 2) √s=510GeV measurements at RHIC to extend the √s coverage of Feynman scaling [9] and 3) light ion collisions at LHC and RHIC, are under consideration. Among them, the idea 2, the RHICf experiment using one of the LHCf detectors, is approved to take data in RHIC Run17 and preparation is on going.

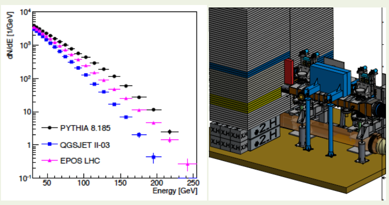

Fig.9 An example of photon spectra expected in a half day of RHICf operation (left) and a possible integration of the RHICf detector (red box) at the STAR interaction point (right).

References

[1] D. D'Enterria et al., Astropart. Phys., 35 (2011) 98-113.
[2] LHCf Technical Design Report, CERN-LHCC-2006-004; O. Adriani, et al. (LHCf Collaboration), JINST 3 (2008) S08006
[3] K.H.Kampert and M.Unger, Astropart. Phys., 35 (2012) 660-678.
[4] T. Mase et al. (LHCf Collaboration), NIM, A671, 129 (2012).
[5] K. Kawade, et al. (LHCf Collaboration), JINST **9**, P03016 (2014).
[6] O. Adriani, et al. (LHCf Collaboration), Phys. Lett. B, 703, 128 (2011).
[7] O. Adriani, et al. (LHCf Collaboration), Phys. Lett. B, accepted (2015).
[8] O.Adriani et al. (LHCf Collaboration), arXiv:1507.08764v1 [hep-ex]
[9] RHICf proposal, arXiv:1409.4860v1 [physics.ins-det]