PROCEEDINGS OF SCIENCE

Prospects of the LHCf Operation in 2022

Ken Ohashi[a,*] **on behalf of the LHCf Collaboration**

[a] *Institute for Space–Earth Environmental Research, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8601, Japan*

E-mail: ohashi.ken@isee.nagoya-u.ac.jp

The Large Hadron Collider forward (LHCf) experiment measures forward neutral particles to improve hadronic interaction models adopted in cosmic-ray air shower simulations. In September 2022, we plan to perform data-taking on proton–proton collisions. We expect statistics that are a factor of 10 greater than those of the previous operation in 2015 for π^0 and η mesons. Moreover, we plan to conduct a joint operation with the ATLAS zero-degree calorimeter. Improvements in energy resolution for hadrons from this joint operation will allow us to select the one-pion exchange process. In this work, we report the prospects for the LHCf operation in 2022.

The Tenth Annual Conference on Large Hadron Collider Physics - LHCP2022
16–20 May 2022
online

*Speaker

PoS(LHCP2022)354

1. Introduction

The origin of ultra-high-energy cosmic rays is one of the most important topics in astrophysics. Understanding it requires knowledge of the energy spectrum and composition of cosmic rays. Ultra-high-energy cosmic rays have been measured by detecting particles from air showers induced by cosmic rays. The composition is estimated by comparing predictions and measurements for observables of air showers (e.g., particles on the ground and the vertical development). The prediction of air showers, however, depends on hadronic interaction models adopted in the simulation. Validation of hadronic interactions by accelerator experiments is essential.

The Large Hadron Collider forward (LHCf) experiment is an experiment measuring very forward neutral particles at the ATLAS interaction point of the LHC. Two LHCf detectors, Arm1 and Arm2, are located 141.05 m away from the interaction point and measure neutral particles in $|\eta| > 8.4$. Each detector consists of two small sampling calorimeter towers made of tungsten plates, GSO scintillators, and position-sensitive layers. Position-sensitive layers are GSO bar hodoscopes for the Arm1 detector and silicon microstrip detectors for the Arm2 detector.

Recently, we published the results from the operation in 2015 on the energy spectrum of the very forward photons [1], neutron energy flow and inelasticity [2], preliminary energy spectrum of very forward π^0 mesons [3], and preliminary energy spectrum of very forward η mesons [4] and gave constraints for hadronic interactions. Moreover, measurements of very forward photons from diffractive dissociation were reported in a joint analysis by the LHCf and ATLAS collaborations [5]. However, large statistical uncertainty exists in π^0 and η meson results because of the limited statistics. Moreover, we could not separate the effects of diffractive mass and particle production from the dissociation system in the joint analysis.

In September 2022, we will conduct another operation using proton–proton collisions with $\sqrt{s}$ = 13.6 TeV. In this operation, we plan to have statistics for π^0, η, and K_S^0 mesons that are greater by a factor of 10 than those in our previous operation. Moreover, the joint operation with the ATLAS experiment including Roman pots and zero-degree calorimeters (ZDCs) is planned. In the joint operation, our two physics targets are diffractive dissociation and the one-pion exchange process. Measurement of pion–proton collisions using the one-pion exchange process at the LHC was proposed in Ref. [6]. It is a unique measurement of high-energy pion–proton collisions, which are dominant in air showers induced by ultra-high-energy cosmic rays. In this work, we report on the prospects for the operation in 2022.

2. Overview of Operation in 2022

The special low-luminosity LHC run including LHCf operation is planned for 19–25 September in 2022 right after the technical stop 1. In this operation, we plan to have statistics for precise measurements of π^0 and η mesons that a factor of 10 greater than those in ~2 days of data collection. Moreover, a joint operation with ZDCs and Roman pots of the ATLAS experiment is being prepared. Figure 1 shows a schematic view of the detectors in LHCf operation. ATLAS-ZDC detectors are installed behind each LHCf detector. ATLAS Roman pots can be installed to measure scattered or produced protons flying in the beam pipe.

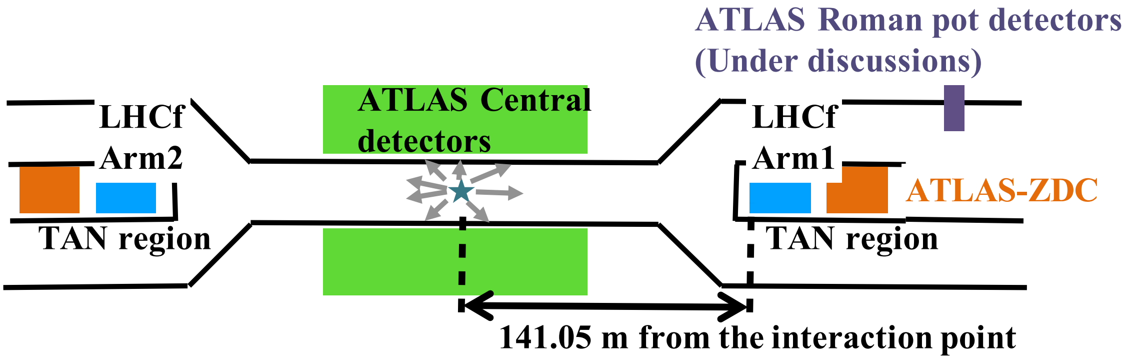

Figure 1: Schematic view of detectors used in the LHCf operation.

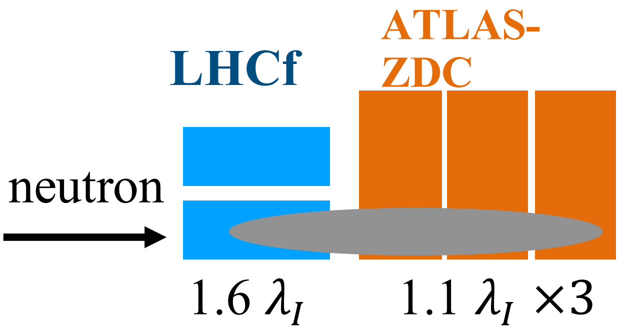

Figure 2: Schematic view of the joint operation between LHCf and ATLAS-ZDC detectors.

Two upgrades were made to the LHCf detectors and their data acquisition system to gain greater statistics than in our previous operation in 2015 [7]: One is the upgrade of the silicon microstrip readout in the Arm2 detector; the other is prescaling the trigger logic to enrich π^0 and η meson candidates.

The energy resolution for hadrons will be improved by joint operation with ATLAS-ZDC detectors. Because the thickness of the LHCf detector is 1.6 interaction lengths, the particles produced in the hadronic shower leaked backward from the detector. By installing ATLAS-ZDC detectors behind each LHCf detector, particles leaked from the LHCf detector are detected by the ATLAS-ZDC detectors. Therefore, we can improve the energy resolution for hadrons from 40% to 20% [7]. Figure 2 shows a schematic view of hadron measurements using LHCf and ATLAS-ZDC detectors.

3. Physics Programs

In operation in 2022, we have the following three physics programs: measurements of π^0, η, and K_S^0 mesons; the one-pion exchange process; and diffractive dissociation.

π^0, η, and K_S^0 mesons Because of the factor of 10 greater statistics than in our previous operation, precise measurements of π^0 and η mesons are expected. A total of 5,000 η candidates are expected

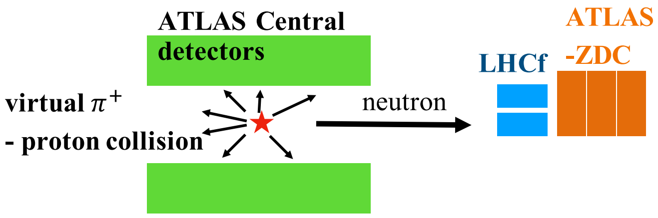

Figure 3: Schematic view of measurements of the one-pion exchange process.

in this operation. Several hundred K_S^0 candidates are expected.

One-pion exchange The one-pion exchange process is characterized by high-energy neutrons in $\eta > 10$ and particles from a collision between a virtual π^+ and a proton in the central region. Particle production in the central region is similar in diffractive dissociation or nondiffractive collisions. One good way to separate the one-pion exchange process is to detect events with a high-energy neutron in the LHCf detector and a large number of tracks in the ATLAS inner detector [8]. These selections will reduce contributions from diffractive dissociation and nondiffractive collisions; in nondiffractive collisions, energy of the forward neutron becomes lower by selecting a large number of tracks in the ATLAS inner detector. Diffractive dissociation only produces a few tracks in the ATLAS inner detector. Figure 3 shows a schematic view of the measurements. Improvements in energy resolution for hadrons help us to select high-energy neutrons.

Diffractive dissociation In the joint operation with ATLAS Roman pots detectors, we have two physics programs. One is the measurement of single diffractive dissociation. The scattered protons and particles from the dissociation systems were measured using the ATLAS Roman pots and the LHCf detector on the other side, respectively. In this case, we can measure the diffractive mass and the energy spectrum of forward neutral particles in the dissociation system simultaneously. The other program is measurements of $\Delta^+ \to p + \pi^0$ from the dissociation system with very low diffractive mass. Because predictions of Δ^+ production in diffractive dissociation vary between hadronic interaction models, we can constrain particle production in diffractive dissociation by using this measurement.

4. Summary

In the LHCf operation in 2022, we plan to make precise measurements of π^0 and η mesons, diffractive dissociation, and the one-pion exchange process. These measurements will help us validate the hadronic interaction models and improve the predictions of air showers.

References

[1] O. Adriani et al., the LHCf Collaboration, Phys. Lett. B 780 (2018) 233–239.

[2] O. Adriani et al., the LHCf Collaboration, JHEP07(2020)016.

[3] A. Tiberio et al., PoS (ICRC2021) 386, https://pos.sissa.it/395/386/.

[4] G. Piparo et al., in this proceedings.

[5] The ATLAS and LHCf Collaborations, ATLAS-CONF-2017-075, https://cds.cern.ch/record/2291387.

[6] V.A. Petrov et al., Eur. Phys. J. C (2010) 65: 637—647.

[7] LHCf Collaboration, "LHCf—Technical Proposal for the LHC Run 3." https://cds.cern.ch/record/2679323.

[8] K. Ohashi et al., PoS (ICRC2021) 190, https://pos.sissa.it/395/190/.