【Grant-in-Aid for Scientific Research (S)】

Exploration of the new physics beyond the Standard Model with rare processes of the Higgs boson

Principal Investigator	High Energy Accelerator Research Organization, Institute of Particle and Nuclear Studies, Professor TOMOTO Makoto Researcher Number:80432235
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Purpose and Background of the Research

●Outline of the Research

In 2012, the Higgs boson was discovered in an experiment using the LHC proton-proton collider at CERN in Switzerland. This revealed that the vacuum of the universe is filled with the Higgs field, the properties of the Higgs field are changed by phase transitions during the cooling process of the universe, and elementary particles acquire mass through interaction with the Higgs field. The Higgs studies conducted by the LHC experiment over the past 10 years have revealed a correlation between the masses of the W and Z bosons and the third-generation of charged fermions, the top (t) quark, bottom (b) quark, and tau (τ) particle, and the strength of their coupling with the Higgs boson and have led to the conclusion that the mass of these particles originates interaction with the Higgs field. On the other hand, it was only found that the introduction of the Higgs field can explain the origin of masses of elementary particles, but there is no guiding principle regarding the Higgs field filled in the universe, and it is not certain whether the form of the Higgs potential is as assumed in the Standard Model(SM). Furthermore, it is not obvious whether the masses of the first- and second-generation fermions were obtained through interaction with the same Higgs field which gives the mass of third-generation fermions (origin of the generation). The purpose of the research is to explore new physics beyond the SM by closely examining two kinds of rare processes which have not been observed so far.

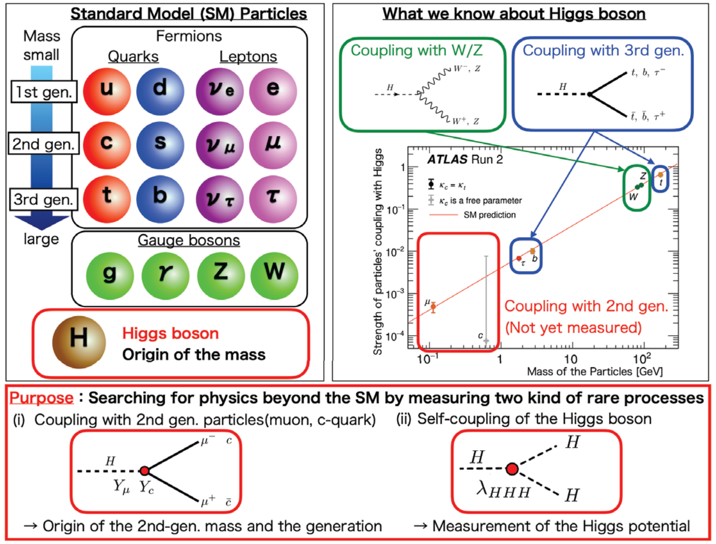

Figure 1. Overall picture of the research. The SM (upper left), What has been revealed in the past 10 years studies (upper right), the rare processes of Higgs boson to be measured in this study (bottom).

●LHC/ATLAS experiment

This research can be achieved by only LHC experiments, which can produce a large amount of Higgs bosons. We have played an active role in the experiment using the ATLAS detector installed at one of the interaction points of LHC from construction and operation of the detector to physical analysis. We have analyzed about 10 million Higgs boson events produced in about 2 x 1016 proton-proton collisions and measured the couplings of W/Z bosons and third-generation fermions with Higgs boson. Run 3 experiment just has begun in the summer of 2022 and is expected to produce about twice as many Higgs boson events as before by the end of 2025.

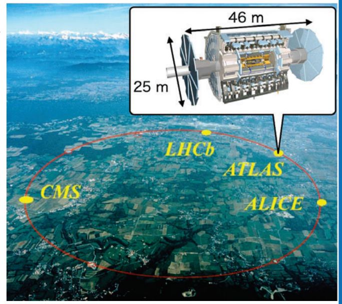

Figure 2.LHC and ATLAS detector

Expected Research Achievements

The purpose of this research is (1) to measure Higgs boson couplings to second-generation fermions by observing Higgs boson decaying into a muon pair and a c-quark pair, and (2) to observe the production of a Higgs boson pair for the measurement of the Higgs boson self-coupling, by using full Run 3 data collected by LHC/ATLAS experiment. In the LHC experiment, two proton beams cross each other at a frequency of 40 MHz. In Run 3, about 50 low-energy proton-proton collision events (pile-up events) occur at each beam crossing. On the other hand, the Higgs boson production frequency is less than 1 Hz, and this valuable event is overlapped with many pileup events. Therefore, we are pursuing the integration of the new inner muon detector, which is newly introduced from Run 3, with the existing system to construct the new muon trigger that can select events containing muons originating from Higgs boson decays with high efficiency, and optimization of the operation of the silicon inner tracker, which has already been exposed to large amounts of radiation, by constantly monitoring the bias voltage to maximize its ability to reconstruct charged particle tracks.

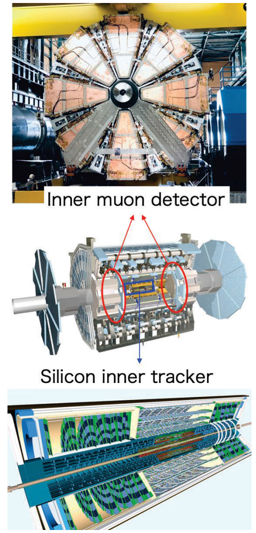

Figure 2.Detectors to be pursued in this research

The pursuit of these improvements in detector performance is one of the originalities of this research, which will enable the studies (1) and (2) listed above. These studies will become more important in the high-luminosity LHC experiment (HL-LHC) starting in 2029. Therefore, we add (3) detector upgrades for the Higgs study at the HL-LHC.

For study (1), we aim at the discovery of the Higgs decays to muon using full Run 3 data. Combining this work with an updated measurement of the couplings of third-generation fermions, we measure the couplings of t-quark, b-quark, tau, and muon with less than 10% accuracy, and include the upper bound on the c-quark coupling. For study (2), according to the SM, it is difficult to discover the pair production of the Higgs boson with full Run 3 data. On the contrary, if significant observations are made with full Run 3 data, it will be a sign of new physics decaying into Higgs boson pairs. We search for new physics decaying into a Higgs boson pair. For study (3), we develop new trigger algorithms incorporating machine learning and silicon pixel detectors with high radiation tolerance. These are expected to have a ripple effect on the verification of infrastructures, the medical, and engineering.

Homepage Address, etc.	https://atlas.cern/ E-mail: makoto.tomoto@kek.jp