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Can unknown physics be seen in interactions between Higgs bosons?

Since the launch of the Large Hadron Collider, there has been ongoing research there into Higgs bosons and a search for traces of physics beyond the existing model of elementary particles. Scientists working at the ATLAS detector has combined both goals: with the latest analysis it has been possible to expand our knowledge of the interactions of Higgs bosons with each other, and stronger constraints on the phenomena of 'new physics' have been found.

An undisputed success of the Large Hardon Collider (LHC) is the discovery of the last missing element of the Standard Model: the Higgs boson, responsible for the origin of the mass of elementary particles. There is also a disappointment: the persistent absence of any trace of physics beyond this model. Scientists at the facility of the European Organisation for Nuclear Research (CERN) in Geneva are therefore trying to conduct their current research in such a way as to combine more precise measurements of the properties of the Higgs boson with further searches for 'new physics'. The study just published is an example of this approach. In it, physicists from the ATLAS experiment focused on events leading to the creation of two Higgs bosons, which would then decay into multiple particles of the lepton family (mainly electrons and muons). The results are presented in the *Journal of High Energy Physics*.

The production of Higgs boson pairs can occur within the Standard Model itself. It is such a rare process here that it has not been possible to observe it in the data collected so far. There are, however, theoretical models describing phenomena beyond the Standard Model, predicting the production of Higgs boson pairs with a higher probability. Observing instances of this sort of production using data already collected would confirm the existence of a hitherto unknown class of physical phenomena. It is therefore not surprising that for the scientists in the ATLAS experiment, this very process became the starting point for the analysis described above.

"Experimental studies of the interactions of Higgs bosons with each other encounter a fundamental problem. It is this: in proton collisions at the LHC, Higgs bosons appear so infrequently that so far not a single event of Higgs boson pair production has been detected, which at first glance seems absolutely necessary if we want to look at interactions between these particles. How, then, can we study a phenomenon that has not yet been observed?" asks Dr. Bartlomiej Zabinski, a physicist at the Institute of Physics of the Polish Academy of Sciences (IPJ PAN) who coordinated the international team responsible for this analysis.

Within the Standard Model, increasingly precise predictions can be made about the probabilities of various known processes. A rationale for suggesting unexpected properties of Higgs bosons or the existence of new physics would be a discrepancy between theoretical predictions and actual data from the LHC detectors. Operating solely within the framework of the Standard Model, the physicists in the ATLAS experiment therefore simulated (together with the background) the signals that should appear in the detectors in the event of two Higgs boson phenomena, and then normalised the results according to the expected amount of data coming from their detector. The final step was to compare the values thus obtained with those derived from previous observations. The use of machine learning based on decision trees helped in the search for these rare processes.

“Our analysis of double Higgs boson production events in the final state with multiple leptons complements the studies already carried out on other final states. So far, we have not noticed anything in the data from our detectors that disagrees with the Standard Model. However, this result does not rule out the possibility of the existence of ‘new physics’ phenomena, but only informs us that their possible influence on the production of Higgs boson pairs remains too weak to be seen in the data collected so far,” concludes Dr. Zabinski.

In the coming years the LHC is to undergo a major upgrade. The intensity of the beams will then increase tenfold, resulting in a significant increase in the number of recorded proton collisions. The limitations imposed by the current analysis on the production and parameters describing the interactions of Higgs bosons allow physicists to hope that perhaps already at the beginning of the next decade it will be possible to select the first events of double Higgs production from more data and to verify today's predictions in direct observations of the phenomenon.

On the Polish side, the research was co-financed by the National Science Centre.

The Henryk Niewodniczański Institute of Nuclear Physics (IFJ PAN) is currently one of the largest research institutes of the Polish Academy of Sciences. A wide range of research carried out at IFJ PAN covers basic and applied studies, from particle physics and astrophysics, through hadron physics, high-, medium-, and low-energy nuclear physics, condensed matter physics (including materials engineering), to various applications of nuclear physics in interdisciplinary research, covering medical physics, dosimetry, radiation and environmental biology, environmental protection, and other related disciplines. The average yearly publication output of IFJ PAN includes over 600 scientific papers in high-impact international journals. Each year the Institute hosts about 20 international and national scientific conferences. One of the most important facilities of the Institute is the Cyclotron Centre Bronowice (CCB), which is an infrastructure unique in Central Europe, serving as a clinical and research centre in the field of medical and nuclear physics. In addition, IFJ PAN runs four accredited research and measurement laboratories. IFJ PAN is a member of the Marian Smoluchowski Kraków Research Consortium: “Matter-Energy-Future”, which in the years 2012-2017 enjoyed the status of the Leading National Research Centre (KNOW) in physics. In 2017, the European Commission granted the Institute the HR Excellence in Research award. As a result of the categorization of the Ministry of Education and Science, the Institute has been classified into the A+ category (the highest scientific category in Poland) in the field of physical sciences.

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SCIENTIFIC PUBLICATIONS:

“Search for non-resonant Higgs boson pair production in final states with leptons, taus, and photons in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector”
The ATLAS collaboration
Journal of High Energy Physics 2024, 164 (2024)
DOI: 10.1007/JHEP08(2024)164

LINKS:

http://www.ifj.edu.pl/
The website of the Institute of Nuclear Physics, Polish Academy of Sciences.

http://press.ifj.edu.pl/
Press releases of the Institute of Nuclear Physics, Polish Academy of Sciences.

IMAGES:

IFJ241106b_fot01s.jpg **HR:** http://press.ifj.edu.pl/news/2024/11/06/IFJ241106b_fot01.jpg
Secondary particle tracks recorded during a proton collision inside the ATLAS detector, indicating the presence of a single Higgs boson in the event. (Source: IFJ PAN / CERN / ATLAS Experiment)