

Warsaw, 27 July 2016

Polish muon hunters increase the research potential of the LHC

As the beams of the LHC accelerator start colliding at maximum energies, the detectors become inundated by a flow of secondary particles, including muons. The challenging task of quickly identifying the most interesting collisions within the CMS detector, one of the main experiments at the LHC, is handled by a special selection system. Having been recently revamped and modernized by physicists and engineers from Poland, the system is now playing a key role in the search for new physical phenomena.

High-energy collisions of protons or lead nuclei generate huge numbers of particles. Physicists usually love to have all the they can get, because the more data they have, the more credible are their resulting analyses and conclusions. But at the LHC accelerator at CERN, such collisions are quite simply too numerous and recording all of them for subsequent analysis is unfortunately well beyond today's technological capabilities. The most interesting cases therefore need to be picked out selectively from this onslaught of data, taking just a few microseconds to make decisions and doing so millions of times a second. Since the CMS (Compact Muon Solenoid), one of the four main detectors for the LHC, was first placed into operation, the preliminary selection of data was partly handled by a muon trigger which Polish physicists had made a sizeable contribution to building. This system has recently undergone a thorough modernization and is now starting work in the new cycle of accelerator exposures. It is now significantly more accurate at detecting muons, particles that are products of the breakup of other particles appearing in collisions.

"Muons, elementary particles with characteristics similar to those of electrons, only around 200 times more massive, carry precious information for us, based on which we recreate how the original collisions proceeded. It was in part thanks to muons captured by our selection system that the famous Higgs boson was successfully discovered," says Asst. Prof. Marcin Konecki from the Faculty of Physics, University of Warsaw (FUW).

A considerable share of the current, modernized muon trigger system for the CMS experiment was designed and built by the Faculty of Physics, University of Warsaw in collaboration with the Warsaw University of Technology and the National Center for Nuclear Research in Świerk, under a grant from Poland's National Science Centre. Physicists, electronics specialists, engineers, technicians and students worked together to devise new collision-selection algorithms and create the software for carefully chosen electronics boards, which were then carefully tested. The use of modern electronics helped significantly reduce the size of the device.

"In successive cycles of operation the LHC will be increasing its particle energies, and the higher the energy the more secondary particles will be created in the collisions. The things are even more challenging, since the accelerator is continually increasing its luminosity, which is a measure of the intensity of the collisions and depends on the number of particles circulating in the accelerator and how they are packed. As a result, a significantly higher number of collisions are now occurring per

unit of time. All of this is making greater and greater demands of the muon selection system,” Konecki says, explaining the need for the modernization project.

Within the CMS detector, beams of protons accelerated nearly to the speed of light intersect every 25 nanoseconds. Each such beam intersection results in a few dozen interactions, each of which may give rise to many secondary particles. The muon trigger’s job is to very quickly and preliminarily identify, within this flurry of particles, muons that have very high transverse momentum, in other words those which flew out of the collision point with high energy and inclined at a significant angle with respect to the direction of the beam.

The location where the beams intersect in the CMS detector is surrounded by several cylindrical layers of detector chambers, situated in the field of a gigantic superconducting magnet 7 m in diameter and 13 meters long, generating a tremendous magnetic field (nearly 4 tesla) inside a coil. The central portion of the detector, known informally as the barrel, is enclosed on either side by flat, circular endcaps containing further detector chambers. The overall length of the main portion of the detector is around 21 m, with an external diameter of around 15 m.

“To identify a muon, one has to detect signals from many detector chambers. They have to come at the right time following a collision and in the right sequence. One also has to bear in mind that, being a charged particle, a muon will follow a curved path through a magnetic field. Within the CMS detector, that field changes: it is oriented one way along the axis of the beam, and the other way far from the beam. A muon moves through such a field along a path that looks like an asymmetrically stretched letter S. The chambers that it activates do not lie along a straight line, making describing the collision difficult. That is why the identification of muons in the trigger involves comparing the tracks they leave behind against model patterns. This is further complicated by random energy losses, multiple scattering, noise, making analysis truly challenging...” Dr. Konecki explains.

...and that’s not the end of the complexities. In 2012, Polish physicists drew the attention of the CMS experiment community to the overlaps between the barrel and the endcaps. The geometry of the detector system is uniform and relatively simple within the endcaps (flat circles) and barrel (the lateral surface of a cylinder), but not where they overlap. Moreover, different types of detectors were mounted in the barrel and endcaps, and along the overlaps all of them had to be taken into consideration – and there are as many as 18 layers of detector chambers here! Moreover, it is precisely in the overlap region that the magnetic field changes orientation. For these reasons, under the influence of suggestions from the Polish physicists, the CMS experiment made the decision to recognize the overlap region a separate, third region for the purpose of analysis, separate from the barrel and endcaps themselves. It was dubbed the Overlap Muon Track Finder (OMTF).

The current modernization of the trigger required better and more precise algorithms to be devised for comparing the activation signals from the detection chambers against a set of respective patterns. The patterns themselves needed to be worked out from scratch, in a more universal way, ensuring that analysis could be completed within the allotted rigorous timeframe.

The OMTF system, constructed by a group from Poland, consists of just two cases of electronics, each of which containing six trigger boards. The design and programming of the whole were made to facilitate its easy expansion in the future, to keep pace with the requirements imposed by the constantly growing luminosity of the LHC accelerator. For the several undergraduate and doctorate students who took part in building, optimizing and launching the system, this has offered them not only excellent opportunities for interesting thesis work, but also an amazing scientific adventure – as is confirmed by A. Byszuk, one of the scholarship-holding doctorate students involved in the OMTF project.

The CMS experiment at the LHC accelerator brings together more than 40 countries, 200 research institutions, 2700 physicists and 1000 engineers and technicians; all told there are more than 4,300

people involved. The research being done here concerns some of the fundamental questions of modern science: How did matter arise? How does it differ from antimatter? Do any other elementary particles exist, other than those now known? What are dark matter and dark energy, the dominant components of the Universe? And why do we live in a Universe with three spatial dimensions? One spectacular success for the CMS experiment came with its contribution to the detection of the Higgs boson, a particle confirming the existence of a mechanism imparting mass to other elementary particles.

Physics and Astronomy first appeared at the University of Warsaw in 1816, under the then Faculty of Philosophy. In 1825 the Astronomical Observatory was established. Currently, the Faculty of Physics' Institutes include Experimental Physics, Theoretical Physics, Geophysics, Department of Mathematical Methods and an Astronomical Observatory. Research covers almost all areas of modern physics, on scales from the quantum to the cosmological. The Faculty's research and teaching staff includes ca. 200 university teachers, of which 88 are employees with the title of professor. The Faculty of Physics, University of Warsaw, is attended by ca. 1000 students and more than 170 doctoral students.

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RELATED LINKS:

<http://cms.web.cern.ch/>
CERN website.

<http://cms.fuw.edu.pl/>
Warsaw Group at CMS.

<http://www.fuw.edu.pl/>
Faculty of Physics, University of Warsaw.

<http://www.fuw.edu.pl/informacje-prasowe.html>
Press office of the Faculty of Physics, University of Warsaw.

IMAGES:

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Technicians from the University of Warsaw at the muon trigger in CMS experiment at the LHC accelerator. (Source: FUW)