LLR-Ecole Polytechnique
M2 High-Energy Physics PHENIICS doctoral school
Université Paris-Saclay

Thesis proposal 2018

Title: *Development of a dedicated trigger system using the information from the high-granularity upgraded calorimeter for LHC Phase II and measurement of the Higgs boson production mode accompanied of a top quark pair.*

Laboratory/ research team: Laboratoire Leprince Ringuet, Ecole Polytechnique. The CMS group at LLR is currently formed by 12 permanent physicists, 2 post-docs and 7 PhD students. It is a founding member of the CMS Collaboration. It has designed and built the ECAL L1 trigger and it is responsible for its daily operation and monitoring. The group has major involvement in particle reconstruction and identification (electrons, taus, particle flow). It is involved in Electroweak (di-bosons, triple gauge couplings, etc...), Heavy Ions and Higgs physics. The group is one of the main protagonists for the discovery of a Higgs boson and the first measurement of its properties. It has been playing a leading role in some of the high priority Higgs analysis of CMS (H to tau leptons, H to ZZ and to 4 leptons in various production modes and HH to bbtautau or ttH with H going to tau leptons). It has managed to develop strong collaborations with physicists from Torino (INFN), Split (FESB), CERN, Imperial College and Johns Hopkins University. The group is also strongly involved in the development of the Phase II CMS Upgrades with major responsibilities in the mechanics, trigger and software algorithms of the future endcap calorimeters (HGCAL).

Overview of the research: The CMS (Compact Muon Solenoid) experiment aims at studying the results of proton collisions produced by the LHC (Large Hadron Collider) at CERN. The discovery of the Higgs boson is a great leap forward as the corresponding mechanism states that particles masses are the result of an interaction with the associated scalar field. The nature of that field is being studied in details and this will occupy the CMS collaborators for the next years. The characterization of the Higgs sector as well as the search for new physics will require the full capabilities of the LHC. Upgrades are also foreseen along the way to reach much higher luminosities (>$5x10^{34}cm^{-2}s^{-1}$) during this Phase II starting in 2026. The CMS experiment deploys a 14000 tones detector equipped with advanced electronics to track and identify precisely all the particles produced from the proton collisions. Although CMS has shown excellent performance, it will undergo major upgrades, which include a new data acquisition system and an innovative Endcap calorimeter to fully exploit the high luminosity conditions.

The thesis work proposed here will focus on taking advantage of the newer analysis and selection techniques to study the challenging Higgs boson production mode associated with a top quark pair. This channel is of particular interest as it probes the Yukawa coupling of the Higgs boson to the top quark. The final state considered here is the Higgs boson decaying into multiple leptons. The precise measurement of this coupling can be used to indirectly constrain possible physics processes beyond the Standard Model. The analysis of the LHC Run I (2010-2013) and Run II (2015-2018) are currently ongoing and the plan is to produce legacy analysis results during the year 2020. This period coincides with the first year of this thesis where a lot of aspects such as combinations within CMS (and with ATLAS) will be carried out. A total of 150 fb-

1 of data are available from the Run II alone and the PhD student is expected to take part of this effort and to help converging toward a publication with unprecedented statistics. Other aspects of the analysis will have to be improved such as the online selection and the optimization or implementation of new signal extraction methods (such as the Matrix Element Method, Deep Neural networks or even Machine Learning). A task will specifically be dedicated to estimate precisely the background contributions, which are currently the limitation factor in systematics errors. As the Run III starts in 2021, the student is expected to participate to the restart of the LHC and live through the commissioning period of the CMS detector with the first collision data. As the LLR group is responsible for the electron, photon and tau lepton triggers, the optimization of these selection algorithms is essential to the success of the physics program. As the final states considered here include leptons, this work will benefit the analyses pursued as described above. This thesis includes the first look at the Run III data, which may reveal unexpected results.

The LLR group is responsible for designing the mechanics and the trigger system of the Phase II upgrade of the Endcap calorimeter. The High-Granularity Calorimeter (HGCAL) is among the most challenging project of the CMS Phase II upgrade program. With 6 million channels, The HGCAL will be the first imaging calorimeter to be implemented in a high-energy physics experiment. Among the many aspects of this project, the student will actively participate to the development of the trigger system based on this innovative calorimeter technology. The expertise of the group in matter of trigger design will be directed towards the implementation of sophisticated algorithms to reconstruct, identify and isolate leptons in the forward region of the detector. The multiplicity of particle and pile-up events will render this task particularly complicated and will require the need for particle flow technique in the heart of the electronics layer of the trigger and data acquisition system of the experiment. This thesis includes an original work and development of these techniques where the student can propose new approaches. The progress in R&D for the project will imply a lot of testing and validations of the component in test beams or using cosmic data.

These contributions are expected to have a large impact within the collaboration. The recorded data will be analyzed to study the Higgs boson final state mentioned above with the promising analysis technique of the Matrix Element Method and Machine Learning in order enhanced signal discrimination with background. This thesis offers the opportunity to participate to very interesting physics at the energy frontier. The balance between advanced data analysis techniques and more technical activities will allow the student to gain expertise in various aspects of the field. The student contributions will be presented to collaborators and in international conferences to ensure visibility among a wide scientific community.

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