PhD thesis subject Proposal 2018

Measuring the top quark Yukawa coupling using multi-leptons decays of the Higgs boson with the CMS detector

Scientific Context

The discovery of the Higgs boson at the Large Hadron Collider (LHC) in 2012 by the ATLAS and CMS experiments [1][2] is a major breakthrough in the understanding of the fundamental interactions. Precisely measuring its properties and coupling to the fundamental fields is a unique way to understand its role in the electroweak symmetry breaking (EWSB) while providing a portal to new phenomena.

The couplings to gauge vector bosons is now firmly established through the observation of the bosonic decays of the Higgs boson ($H\rightarrow ZZ$, WW and $\gamma\gamma$). However, the direct couplings to heavy quarks are still to be observed and measured accurately. In particular, the top quark, being the heaviest one, has the strongest Yukawa coupling (y_t) to the Higgs boson and could thus play a special role in EWSB. **Any departure from the Standard Model (SM) expectations would be a clear sign of new physics (NP).** In the SM, one could bring insights on the value of y_t by measuring loop-induced processes such as gluon fusion production mode. However, beyond-the-SM particles may also participate to these loops. It is **therefore crucial to directly measure y_t** by looking at processes where a Higgs boson is radiated from a top quark, i.e. associated production with a single (tHq) or a pair (ttH) of top quarks. The resulting experimental final states are rich, due to the multiple decay possibilities for both the Higgs and the top quark. The channels with leptons coming from the Higgs boson decays ($H\rightarrow WW$, ZZ,$\tau\tau$) are among the most promising ones. Evidence of the ttH process has recently been released by the ATLAS and CMS experiments [3]. However, the corresponding **analyses are already limited by systematics** and making an unambiguous observation and precise measurements will require more than just accumulating extra data.

By the end of 2018, the LHC will deliver up to 150 fb^{-1} of proton-proton collisions data at $\sqrt{s}$ =13 TeV. It will then stopped for a period of 2 years called Long Shutdown 2 (LS2) for improvements of the acceleration chain. It will re-start in 2021 for 3 years.

Thesis project

The main objective of the PhD student is to observe the ttH process, with $H\rightarrow WW$, ZZ,$\tau\tau$, followed by their leptonic decays, and provide an accurate measurement of the top quark Yukawa coupling.

The thesis will start in Fall 2018, before the end of Run II and the beginning of LS2. It will be the perfect time for the PhD student to participate to the development of new methods in order to drastically reduce the systematic uncertainties on the ttH analysis: advanced lepton selection tools using state-of-the-art machine learning technics (such as "Deep" Neural Network), new background estimation techniques or Matrix Element Method to further improve the signal to background separation [4].

The final result obtained will be then combined with the other decay modes of the Higgs ($\rightarrow$bb,$\gamma\gamma$) for the final Run II CMS publication. Any possible departure from the Standard Model prediction could reveal uncharted territories.

Depending on the interests of the PhD student, a participation to the R&D on the High Granularity CALorimeter (HGCAL) project, aiming at replacing the endcap calorimetry of CMS for the High Luminosity phase of the LHC (HL-LHC) can also be envisaged: data analysis of test beams with prototypes or development of innovative Particle Flow reconstruction algorithms.

Host team at Laboratoire Leprince Ringuet (École Polytechnique)

The CMS group at LLR is currently formed by 13 permanent physicists, 4 post-docs and 6 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$\rightarrow$2 taus, H$\rightarrow$ZZ$\rightarrow$4 leptons in various production modes, HH$\rightarrow$bb$\tau\tau$ or ttH$\rightarrow\tau\tau$). It has managed to develop strong ties with physicists from Torino (INFN), Split (FESB), CERN and Johns Hopkins University.

The group is also strongly involved in the development of HGCAL, an innovative Si-based sampling calorimeter that will replace the CMS endcaps calorimeters for HL-LHC starting in 2023. It has responsibilities in the mechanics, trigger and software developments.

Master and doctoral school

M2 High-Energy Physics
PHENIICS doctoral school – Université Paris-Saclay

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References

[1] G. Aad et al.[ATLAS Collaboration], *Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC*, Phys.Lett.B 716 (2012) 1

[2] S.Chatrchyan *et al.* [CMS Collaboration], *Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC*, Phys.Lett.B 716 (2012) 30

[3] CMS Collaboration, *Search for production of a Higgs boson and a single top quark in multilepton final states in proton collisions at s√=s= 13 TeV*, CMS-PAS-17-005.
https://cds.cern.ch/record/2264553/files/HIG-17-005-pas.pdf

[4] For instance: CMS Collaboration, *Search for the associated production of a Higgs boson with a top quark pair in final states with a τ lepton at s√=s= 13 TeV,* CMS-PAS-17-003
https://cds.cern.ch/record/2257067/files/HIG-17-003-pas.pdf