

PhD Proposal 2026*Study of Higgs Self-Coupling with multi-lepton channels
and modern machine learning techniques***Scientific Context**

The discovery of the Higgs boson (H) at the Large Hadron Collider (LHC) in 2012 by the ATLAS and CMS collaborations 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 bosons are now firmly established. All major production modes have been observed as well as the Yukawa couplings to the third generation fermions. The measurement of Higgs boson couplings is now entering a precision era. All results are so far in agreement with the predictions from the Standard Model (SM), within the current experimental and theoretical uncertainties (ranging from about 10 to 20%).

The exploration of the scalar sector is just at the beginning and remains **one of the best portal to reveal uncharted territories**. The physics program is extremely rich: precision measurements of couplings (where any departure from the SM expectations would be clear sign of new physics), measurement of the Higgs boson potential (via the double Higgs boson production), searches for additional Higgs, rare or forbidden decays, Dark Matter (via “invisible” decay), ...

The LHC has delivered up to 150 fb^{-1} of proton-proton collisions data at $\sqrt{s} = 13 \text{ TeV}$ from 2016 to 2018 and more than 300 fb^{-1} at $\sqrt{s} = 13.6 \text{ TeV}$ from 2022 to 2025. About 400 fb^{-1} are expected at the end of Run 3 data taking by mid-2026. This enormous amount of data will allow to **probe the scalar sector at unprecedented scales**.

In parallel, the experiments are preparing the High Luminosity phase (HL-LHC) aiming at accumulating ten times more data in 10 years and starting in 2030. The extreme data taking conditions foreseen (very high levels of radiations and pile-up) implies major upgrades of the CMS experiment. In particular, the endcap calorimeters will be replaced by an innovative Si-based “imaging” calorimeter called “High Granular CALorimeter” (HGCal) currently under development.

Thesis project

The main objectives of the thesis will be to study the Higgs self-coupling (λ_{HHH}), one of the least known parameters of the scalar sector with high precision multi-leptons channels (e.g., $H \rightarrow ZZ \rightarrow 4 \text{ leptons}$). Measuring λ_{HHH} is of utmost importance as it defines the shape of the Higgs potential, which control the Higgs mechanism. Any deviations from the SM value could have implications on the Electroweak phase transition or the stability of the electroweak vacuum, thus be sensitive to new physics in a unique way.

At the LHC, the self-coupling can be probed via the radiative corrections modifying some observables of on-shell (e.g. differential cross-section of the Higgs boson transverse momentum), off-shell Higgs (modification of the four-lepton invariant mass line shape) or measurement of the production of di-Higgs bosons ($HH \rightarrow bbZZ$).

The thesis will start in Autumn 2026. It will ultimately profit from the entire amount of data collected from 2022 to 2026, thus promising to provide **legacy measurements** which won't be overcome until several years.

In particular, as the measurements described above involve various physics process which interfere, one of the goals of the thesis will be to drastically improve the sensitivity of these analysis with cutting edge machine learning techniques like *Neural Simulation-based Inference (NSBI)*. It is also expected that the candidate will contribute to the combination of the measurements to achieve the best precision on λ_{HHH} and constraint Beyond Standard Model physics.

A part of the thesis will be also devoting to more technical work: participation of the assembly & testing of the HGCal device or work on innovative algorithms for electron reconstruction and identification, depending on the interest of the candidate.

Internship

A Master-2 internship, prior to the thesis, will focus on the development of the $HH \rightarrow ZZ \rightarrow bb4l$ (where l =electron or muons) Run 3 analysis, optimizing the observable used to separate the searched signal from the backgrounds (e.g. with Deep Neural Networks) and make a first implementation of NSBI for the extraction of the final results.

Host team at Laboratoire Leprince Ringuet (École Polytechnique)

The CMS group at LLR is currently formed by 13 permanent physicists, 4 post-docs and 15 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 $t\bar{t}H \rightarrow \tau\tau$). It has developed strong ties with physicists from many other groups in the CMS Collaboration from Europe and the USA.

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).

Internship Supervisor Director

Christophe Ochando, the main supervisor, is a former $H \rightarrow ZZ$ CMS sub-convenor and is currently coordinating the team, gathering physicists from Johns Hopkins University, Torino or University of Split, which provides in CMS the main workflow for the $H \rightarrow ZZ \rightarrow 4$ leptons analysis. He is also convening the CMS electron reconstruction working group.

The supervisor will have daily informal meetings with the student to discuss progress or difficulties. The student will also report his work frequently to the LLR group meetings as well as to CMS internal meetings.

Candidates should hold a master degree in high-energy physics. Frequent travel to CERN is foreseen during the thesis.

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A handwritten signature in black ink, appearing to read 'Ochando', with a stylized flourish extending from the end.