INSTITUT POLYTECHNIQUE DE PARIS
Laboratoire LEPRINCE-RINGUET

PhD Proposal 2024

Measurement of Higgs boson properties with multi-lepton channels and development of electron selection algorithms with the CMS experiment at the LHC

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 TeV from 2016 to 2018 and about 200 fb^{-1} at $\sqrt{s}$ =13.6 TeV from 2022 to 2024. More than 300 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 **search for new physics** by make high precision measurement of the Higgs boson couplings with multi-leptons channels (eg, H→ZZ→4 leptons).

The thesis will start in Autumn 2025. 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.

As some of the measurements may be still dominated by statistical uncertainties and in addition to the new data, it is crucial to enlarge the phase space of the analysis by exploring Higgs boson events decaying to particles with lower momentum than previously considered (ie, down to 3 GeV for muons) or lower Z boson invariant mass (below 12 GeV). This will require the development of **innovative algorithms** to reconstruct those leptons efficiently and new tools using stat-of-the-art Deep-Neural Net (DNN) technologies to reject the important backgrounds perturbing the measurements.

Many observables will be used to constraint the Higgs boson couplings: inclusive and differential cross-sections (e.g. Higgs boson transverse momentum), fully exploiting the kinematics of the Higgs boson production modes and decay products.

In particular, a Master-2 internship, priori the thesis, will focus on the development of new innovative DNN to identify electrons in CMS, especially at low momentum (below 10 GeV). $H \to ZZ \to 4$ leptons). Depending on the interest of the candidate, this work will continue during the thesis or can be ported to the reconstruction algorithms of the HGCAL device.

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 ($H \to 2$ taus, $H \to ZZ \to 4$ leptons in various production modes, $HH \to bb\tau\tau$ or $ttH \to \tau\tau$). 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 $H \to ZZ$ CMS sub-convener 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 $H \to ZZ \to 4$ 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.

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