# M2 internship and PhD thesis subject proposal 2021

**Title**: Search for double Higgs boson production in the bbττ channel in the CMS experiment at the LHC and particle flow reconstruction with the high granularity calorimeter.

**Laboratory/Team:**
The CMS group at the Laboratoire Leprince Ringuet (Ecole Polytechnique, Palaiseau)

**Thesis context:**
After the discovery of the Higgs boson in 2012 at the LHC [1,2], the properties of the newly discovered boson have been studied during the Run 1 and the Run 2 and are in line with those predicted by the theory [3]. To go further, the Brout-Englert-Higgs mechanism itself should be studied, which can be done through the determination of the self-interaction parameter, $\lambda_{HHH,}$ which is responsible for the shape of the Higgs field potential itself and drives the double Higgs boson production.
The discovery of the double Higgs boson production is only expected during the High-Luminosity phase of the LHC (HL-LHC), but it is already being studied with the existing data [4] and will further explored during the upcoming Run 3 (starting in 2022), in particular the production through the so-called Vector Boson Fusion (VBF) mechanism can already bring interesting constraints on the quadrilinear $\lambda_{VV}$ coupling. The VBF production is usually characterised by the presence of high-energy jets in the endcap regions of the detector.
In view of the HL-LHC, the detector will undergo a major upgrade, in particular of the endcap calorimeters. The collaboration made the ambitious choice a high-granularity calorimeters, HGCAL[5], to replace the existing ones. To optimally exploit the fantastic capabilities of these novel detectors, the reconstruction algorithms should be entirely redesigned.

**Thesis subject:**
The first part of the thesis will be dedicated to the development of reconstruction algorithms exploiting the HGCAL detector. This work will be carried out within a “particle flow” reconstruction scheme consisting in combining optimally (and possibly using machine learning techniques) the information of the different sub-detectors to identify, and measure the four-vectors of all the particles individually. The possibility to exploit the timing information provided by the timing layer and by HGCAL will be explored. It will serve as qualification task for the student to be included on the CMS author-list.
In the second part of the thesis, the HH→bbττ analysis will be tackled with the Run 3 data and will particularly focus on the VBF production mechanism. Emphasis will be put on setting up data-driven background estimation techniques.
The knowledge thus acquired will be finally use to derive accurate predictions of the sensitivity achievable at HL-LHC.

**Internship subject:**
The internship will consist in simulation-based studies of the behavior of electrons in HGCAL, in particular assessing the performance of the track reconstruction seeding.

**Team**

The student will join the CMS group at Laboratoire Leprince-Ringuet (LLR, Ecole Polytechnique). The group is a founding member of the CMS Collaboration. It has designed and built the ECAL L1 trigger and is responsible for its daily operation and monitoring. The group has major involvement in particle reconstruction and identification (electrons, taus, particle flow), and is involved in Electroweak (di-boson, tri-boson, gauge couplings, ...), Heavy Ions and Higgs physics.

The group is one of the main contributors for the Higgs boson discovery, and for the first measurements of its properties. It has been playing a leading role in some of the high priority Higgs boson analyses of CMS ($H \rightarrow \tau\tau$, $H \rightarrow ZZ^* \rightarrow 4l$, $HH \rightarrow bb\tau\tau$ and $ttH \rightarrow \tau\tau$). 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 for the High-Luminosity LHC, with major responsibilities in the mechanics, trigger and software algorithms of the future endcap calorimeters (HGCAL)

**Contacts**

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**References**

[1] 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, 716:1–29, 2012.

[2] CMS Collaboration. Observation of a New Boson at a Mass of 125 GeV with the CMS Experiment at the LHC. Phys. Lett. B, 716:30–61, 2012.

[3] ATLAS and CMS Collaborations. Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s}$=7 and 8 TeV. J. High Energy Phys. 08 (2016) 045

[4] CMS Collaboration. Combination of searches for Higgs boson pair production in proton-proton collisions at $\sqrt{s}$=13 TeV. Phys. Rev. Lett. 122 (2019) 121803

[5] CMS Collaboration. The Phase-2 Upgrade of the CMS Endcap Calorimeter", Technical Report CERN-LHCC-2017-023. CMS-TDR-019, CERN, Geneva, Nov, 2017.