M2 Internship Subject (2024-2025) at Institut Pluridisciplinaire Hubert Curien (IPHC)
Department of Subatomic Research (DRS)

CMS Team

Exploring new long-lived particles at the LHC: topological signatures by charge and lifetime.

Large Hadron Collider (LHC) has advanced the high-energy frontier of particle physics for over a decade, leading to significant breakthroughs, notably the discovery of the Higgs boson. Currently, the LHC is in its third data-taking period, known as Run 3, which will continue until summer 2026. Compared to Run 2, the center-of-mass energy has increased from 13 to 13.6 TeV, and the maximal instantaneous luminosity has been achieved.

Among the four primary experiments at the LHC, the CMS collaboration pursues an ambitious scientific program. This includes studying the Higgs mechanism and electroweak sector through precision measurements and searches for rare processes. Beyond probing the Standard Model (SM), CMS conducts a wide range of experimental searches for physics beyond the Standard Model (BSM). These phenomena could appear directly—such as through new resonances—or indirectly through enhancements in suppressed processes or deviations from SM predictions.

Experimental searches are often classified based on the expected signatures a theoretical model predicts, which depend on factors such as particle type, decay channels, and lifetimes. Particle lifetimes generally decrease with mass, often reaching extremely short durations ($<10^{-20}$ s) for particles with masses on the order of hundreds of GeV. However, lifetimes can be extended in cases of compressed mass spectra, massive mediators, or feeble couplings. For particles with lifetimes greater than 10^{-13} s, displaced topologies such as vertices, tracks, leptons, photons, or jets may be detected depending on the decay channel. Particles with lifetimes exceeding 1 ns may decay within the calorimeters, potentially producing showers in the muon system. At longer lifetimes, a particle may traverse the entire detector volume. If neutral, it may escape the detector; if charged, it could leave energy deposits in sensitive volumes.

During this internship, the student will focus on scenarios involving heavy, electrically charged, long-lived particles. Various topologies could be explored based on particle nature, electrical charge value (which may differ from unity), and lifetime. The internship's objective is to conduct a literature review on this topic, examining experimental results and phenomenological studies, and to propose a strategy for a new analysis in CMS using Run 2 and Run 3 data.

Several studies have explored fractionally charged particles ($|Q|<1$) [1], multi-charged particles ($2<|Q|<8$) [2], and highly electrically charged objects (HECO) [3] with $|Q|>10$, which lie at the frontier of meta-stable particles. The most recent CMS results are restricted to $|Q|\leq 2$ [4]. For charged particles, ionization signals deposited in central detectors or calorimeters are key indicators. The internship could include a comparative study of various methods used to analyze these signatures. For particles with shorter lifetimes, experimental signatures could include interactions with detector materials, manifesting as short tracks (<1 ns), normal inner tracks (>1 ns), or even muon-like tracks (>10 ns). Particles with sufficient path length might reach detectors with timing capabilities, such as calorimeters, muon chambers, and the upcoming timing layers for the HL-LHC era in ATLAS and CMS. After a literature review, the student will design an analysis strategy to search for multi-charged long-lived particle using Monte Carlo simulations and CMS data. This work could be extended and enlarged during a PhD Thesis.

Internship supervisor : Eric Chabert
Phone : +33 (0)3 88 10 66 31 Email : eric.chabert@iphc.cnrs.fr Research team : CMS