A global search for charged long-lived particles at LHC with the CMS experiment though advanced instrumental exploitation

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The CMS collaboration, which analyzes proton-proton collisions at the Large Hadron Collider (LHC) at CERN, conducts an extensive program of searches for physics beyond the Standard Model. The CMS group at IPHC has focused on signature-based searches dedicated to long-lived particles. As part of previous PhD research, a search for heavy long-lived particles carrying an electric charge was conducted and published [1]. The objective of this thesis is to extend that search to scenarios where the electric charge differs from e.

Beyond the Standard Model (BSM) theories predict a variety of exotic particles, some with electric charges greater than one. Such particles appear in Grand Unified Theories (GUTs), models with vector-like quarks, doubly charged Higgs bosons, and extra-dimensional frameworks. Other models even predict particles with extremely high electric or magnetic charge, such as Q-balls, magnetic monopoles, or dyons. The CMS experiment published a legacy Run 1 paper [2] that included a search for multi-charged particles, covering charges up to $|Q| = 8e$. However, this search was not extended to Run 2 data, despite the increased discovery potential provided by the higher center-of-mass energy and luminosity. In contrast, the ATLAS experiment has conducted dedicated searches on this topic [3][4]. Additionally, the MoEDAL experiment, a smaller dedicated detector, has been successfully installed and is actively investigating the existence of monopoles and highly charged long-lived particles. The primary goal of this PhD thesis is to exploit Run 2 and Run 3 data to produce a legacy result for the search for multi-charged long-lived particles with the CMS detector.

Fractionally charged particles are also well motivated by various theoretical models. The CMS collaboration has published results using Run 2 data [5], demonstrating sensitivity to charges between 0.5e and 0.9e. A common feature among all these searches is the reliance on the ionization signal deposited in the silicon layers of the CMS tracker, which must be abnormally high (low) for multi-charged (fractionally charged) particles. The second goal of this PhD thesis is to develop common tools that will benefit all related analyses. The plan includes working on data selection, calibration, and resolution enhancement through the application of machine learning techniques. Additionally, a dedicated approach will be implemented to improve Monte Carlo simulations by incorporating instrumental effects observed in data, particularly those arising from increased irradiation.

While the Run 2 CMS publication [1] relies on ionization signals, this research will also incorporate timing information from either the muon chambers (outermost detection layers) or the electromagnetic calorimeter (ECAL). In his PhD thesis [6], R. Haeberlé demonstrated the improved sensitivity achieved by utilizing muon chamber timing. Additionally, ECAL timing information could be particularly relevant for multi-charged particles, as their energy loss scales with Q^2, and timing resolution improves at higher energies. The PhD candidate will explore this possibility as part of her/his research.

The IPHC-CMS group plays a key role in the R&D and construction of the future CMS Tracker for the HL-LHC, particularly in the integration of double-sided silicon sensors onto mechanical structures, including electrical, optical, and cooling services. In 2026-2027, approximately 3600 sensors (covering ~72 m² of silicon surface) will be installed and tested in a dedicated area of the laboratory. IPHC is responsible for building and installing the three outermost layers (out of six) of the tracker barrel. While engineers and technicians will handle the installation operations, the selected PhD student, in collaboration with IPHC physicists, will work on module testing, including detector qualification and quality assurance. This instrumental work will ideally complement the student's primary research activities and provide valuable preparation for future involvement in the operation and performance of the CMS experiment.

Further information: http://www.iphc.cnrs.fr/-CMS-.html

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