MAP-fis Essay Proposal, 2013-2014

(*please write in English*)

Supervisor

Name: **Nuno Castro**

E-mail: **nuno.castro@cern.ch**

Title

Search for vector-like quarks using data collected at the run-2 of the LHC

Area

(*Materials, Optics, Condensed Theory, High Energy Theory,....*);

Experimental Particle Physics

Summary of Proposal

A cornerstone of the Standard Model (SM) is the formulation of the electroweak interactions as arising from a spontaneously broken gauge symmetry. Experiments over the past four decades have confirmed this hypothesis with precision, most notably the LEP and SLC collider programs. However, the nature of the symmetry-breaking mechanism is not yet determined. The ATLAS and CMS collaborations reported in 2012 observations of a new particle produced at the CERN Large Hadron Collider (LHC) possessing properties thus far consistent with those predicted for the SM Higgs boson. The default electroweak symmetry-breaking mechanism, whereby a weak-isospin doublet of fundamental scalar fields obtains a vacuum expectation value, therefore remains a valid hypothesis. Even with the existence of a Higgs boson confirmed, the SM cannot be considered a complete description of Nature. For example, the theory does not explain the fermion generations and mass hierarchy, nor the origin of the matter-antimatter asymmetry in the universe. Neither does it possess a viable dark matter particle, nor describe gravitational interactions. The SM is therefore generally regarded as a low-energy approximation of a more fundamental theory with new degrees of freedom and symmetries that would become manifest at higher energy. In fact, the SM violates a concept of naturalness when extrapolated to energies above the electroweak scale, as fine tuning is required to compensate the quadratic mass-squared divergence of a fundamental scalar field Proposed models of physics beyond the SM typically address the naturalness problem by postulating a new symmetry. For example, supersymmetry is a Bose-Fermi symmetry, and the new states related to the SM bosons and fermions by this symmetry introduce new interactions that cancel the quadratically divergent ones. Alternatively, the symmetry could be a spontaneously broken global symmetry of the extended theory. Examples of models that implement this idea are Little Higgs and Composite Higgs models. The new states realizing the enhanced symmetry are generically strongly coupled resonances of some new confining dynamics. These include vector-

like quarks, defined as color-triplet spin-1/2 fermions whose left- and right-handed chiral components have the same transformation properties under the weak-isospin gauge group. Such quarks could mix with like-charge SM quarks, and the mixing of the SM top quark with a charge +2/3 vector-like quark could play a role in regulating the divergence of the Higgs mass-squared.

During the first operation phase of the LHC both the ATLAS and CMS Collaborations developed an extensive search program for vector like quarks. In the absence of an evidence for such particles, constraints on the parameter space of these quarks were obtained. Depending on the decay mode, vector like quarks with masses up to 900 GeV were excluded. The second operation phase of the LHC should allow us to either discover such new quarks or improve the current limits above the TeV scale, which is an important point, since many of the non-SUSY models predicting new quarks require these to have masses at the TeV scale in order to keep the magnitude of accidental cancellation (fine-tuning) at an acceptable level.

During the proposed essay, a study of the sensitivity expected for the search for vector-like quarks in the second operation phase of the LHC will be performed. The work will focus on multilepton topologies and will be integrated in the Portuguese group participating in ATLAS experiment at CERN. The evaluation of systematics uncertainties, testing new strategies to control them, and a close collaboration with the phenomenological community in the interpretation of the experimental results will be a crucial point to fully exploit the potential of the new LHC data.

References

(*to allow students first look at topic*)

1) J.A. Aguilar Saavedra et al, Handbook of vector like quarks: Mixing and single production, Phys. Rev. D88 (2013) 9, 094010.

2) F. del Aguila et al, Observable contributions of new exotic quarks, JHEP 0009 (2000) 011.

3) J. A. Aguilar Saavedra, Identifying top partners at LHC, JHEP (2009) 030.

4) J. Santiago et al., Model-Independent Searches for New Quarks at the LHC, JHEP 1108 (2011).

5) ATLAS Collaboration, Search for pair and single production of new heavy quarks that decay to a Z boson and a third-generation quark in pp collisions at √s =8 TeV with the ATLAS detector, JHEP 11 (2014) 104.

6) ATLAS Collaboration, Search for vector-like B quarks in events with one isolated lepton, missing transverse momentum and jets at √s = 8 TeV with the ATLAS detector, arxiv:1503.05425 (2015).