Research Project

One century of experimental measurements and progress in theoretical physics led to an extremely compact and elegant theory of fundamental interactions between elementary particles, the Standard Model (SM). Its success in reproducing measurements from different experiments in energy regimes spanning over several orders of magnitude is astonishing. Strong, weak and electromagnetic interactions are all described within the same mathematical framework of gauge theories. Although the electromagnetic and weak interactions are related to the same $SU(2)_L$ x $U(1)_Y$ invariance, only the electromagnetic symmetry is manifest in the mass spectrum. The rest of the electroweak symmetry is hidden, that is, it is spontaneously broken. The detailed mechanism through which the breaking happens is not clear, though. The simplest way this could be explained theoretically is through the so-called Higgs mechanism of the SM. This mechanism explain, for instance, why elementary particles have mass. The Higgs mechanism postulates the existence of a new scalar particle, the Higgs boson, whose mass is not theoretically predicted by the SM, but that should be experimentally observable at particle colliders.

The Large Hadron Collider (LHC) is the largest proton-proton (pp) collider ever built. It is located at CERN, Geneva, and its main objective is to finally unravel the origin of the electroweak symmetry breaking. Using the pp collision data at the center-of-mass energy of 7 TeV collected in 2011, ATLAS and CMS, the largest experiments at the LHC, excluded the SM Higgs in the mass range 127-600 GeV, while masses below 114 GeV were already excluded by previous experiments at the electron-positron LEP collider. Thus, the mass range 114 GeV-127 GeV is currently the only one in which a Standard Model Higgs boson can hide, and it is in fact also the range preferred by the electroweak precision tests performed at LEP. In this mass range, the ATLAS and CMS experiments observe an excursion of the observed data from the expected background, that is compatible with the existence of a SM Higgs boson with mass around 125 GeV. However, no claim of discovery is possible at the moment given the small statistical significance of the excess.
In 2012, the LHC will collide protons at a center-of-mass energy of 8 TeV, delivering a number of collisions three times higher than in 2011. The higher energy and larger amount of data will allow to either confirm the "125 GeV" signal or rule out the existence of a SM Higgs by the end of the year. The LHC is scheduled to enter a long technical stop at the end of 2012 to prepare for running at its full design center-of-mass energy of around 14 TeV in early 2015.
In this contest, the scattering of two longitudinally polarized W bosons (WW scattering) is a promising channel to investigate the electroweak symmetry breaking (EWSB) mechanism. In fact, in absence of the Higgs boson contribution, this SM process would violate the unitarity of the diffusion amplitude at a center-of-mass energy of around 1 TeV; thus we know that, in this scenario, interesting physics must emerge at that energy scale. Anyway, the WW scattering carries a direct information about the EWSB mechanism, no matter whether a physical elementary Higgs particle exists or some kind of strongly interacting physics is responsible for this breaking. In fact, even if the "125 GeV" signal is confirmed with high statistical significance by the 2012 data analysis, the energy dependence of the longitudinal WW scattering above the Higgs candidate mass scale will tell us if the SM Higgs boson unitarizes the WW scattering fully or only partially, as predicted in some theoretical models with composite Higgs. Therefore, the study of the WW scattering at high center-of-mass-energy is, in any case, a fundamental milestone in the physics program of the LHC experiments.

Beyond this, it is important to mention that there are many unsatisfactory aspects in the picture depicted by the SM: the hierarchy problem, i.e. the big gap between the electroweak energy scale and the Planck scale at which quantum effects of gravity become strong, is seen as one of its major limitation and has been the driving force for many theoretical developments extending the SM. Although the panorama of alternative new physics models is wide, one the most appealing and popular alternative is represented by the existence of Extra Dimensions. In the original Randall-Sundrum (RS) model, the hierarchy problem of the SM is solved using a theoretical framework that includes a warped extra dimension in which gravity can propagate. The most distinctive feature of this scenario is the existence of spin-2 gravitons whose masses and couplings to the SM are set by the TeV scale. The gravitons appear in experiments as widely separated resonances. Decays of the graviton to pairs of electrons, muons, or photons are traditionally among the golden channels for searches of extra dimensions. Well-motivated extensions of the original RS model address the flavor structure of the SM through localization of fermions in the warped bulk. This picture offers a unified geometric explanation of both the hierarchy and the flavor puzzles in the SM. In this scenario, graviton production and decay with light fermion channels are highly suppressed and the decay into photons are negligible. However the production of gravitons from gluon fusion and their decay into a pair of longitudinal gauge bosons (W_L/Z_L) can be significant. In general, new resonances decaying to a pair of vector bosons are also foreseen by other models of physics beyond the SM such as excited quarks, technicolor, etc..

The research project presented in this document is motivated by the current knowledge in the experimental and theoretical fields discussed above, and it fits well with the physics program of the CMS experiment at LHC, in which I have been working since the beginning of my graduate studies in 2004. In the past 3 years, I have been based at CERN playing a leading role in:
- various searches for new physics beyond the SM using pp collision data;
- commissioning, and detector performance studies of the hadronic calorimeter (HCAL);
- performance studies of missing transverse energy (MET) reconstruction.

At CMS, the HCAL is mainly employed, together with electromagnetic calorimeter ECAL, for the reconstruction of jets and the missing transverse energy in the event, hence playing an important role for physics analyses presented in this proposal. The project is structured in various phases, accordingly with the LHC schedule for the next few years.

a) Search for New Resonances Decaying to Pairs of Vector Bosons

In the first period of the contract, I will search for new physics beyond the standard model by studying the decay of heavy resonances (X) in pairs of vector bosons (VV = WW / WZ / ZZ). The analysis will focus on the semi-leptonic (lvjj and lljj) and fully hadronic (jjjj) final states using the data that will be collected by CMS in 2012 at a center-of-mass energy of 8 TeV. The motivation is twofold. First, these W/Z decay channels have the largest branching fraction, thus allowing to extend the sensitivity to new physics to higher values of resonance mass (i.e. lower cross section) compared to the fully leptonic channels. Second, I already developed a solid expertise in the study of these final states during the past years of analysis in CMS, both in terms of analysis methods and reconstruction of physics objects.

Using the first pp data collected by CMS in 2010, I took a leading role in the search for pair production of leptoquarks (LQ) in the LQLQbar–>eejj final state [1] and I was the contact person for the search LQLQbar–>evjj [2]. Both results have been published in well-known scientific journals. In addition, I have been supervising a PhD student from Princeton University to update both analyses with the almost 5 fb-1 of data collected in 2011. I have also been member of the *"Analysis Review Committee"* (ARC) for the scrutiny of a public CMS result within the collaboration: search for Randall-Sundrum gravitons decaying into a massive jet plus missing transverse energy final state (G–>ZZ–>vvjj) [3]. I am currently involved in a search for new resonances that decay to a pair of jets (dijets) which is aiming to deliver a public result in early 2012. The fully hadronic X–>VV–>jjjj channel mentioned above can be seen an extension of this more inclusive dijet search. At high resonance mass, the vector bosons have large energy and transverse momentum (pT). The hadronic decay products of each vector boson are then merged into a single massive jet, and the final state effectively has a dijet topology. This effect, also present in the leptonic W/Z decays, opens challenging experimental issues for the reconstruction of these boosted topologies.

b) Study Techniques for the Reconstruction of Boosted Vector Boson Decays
The experimental challenge for the study of heavy VV resonances in semi-leptonic and fully hadronic final states consist in being able to identify.