Facoltà di Scienze Matematiche, Fisiche e Naturali

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Search for new particles decaying into diboson final states in proton-proton collisions at $\sqrt{s} = 13$ TeV

Ph.D. Project

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Standard Model and LHC

Particle physics, my research field, is the study of the basic elements of matter and the forces acting among them. One century of experimental measurements and progresses 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. The discovery of the Higgs boson (H) has been another confirmation of the SM predictions. Despite the success of this theory, there are still some open questions that cannot be answered by the SM (e.g. neutrino masses, the fact that 20% of the universe is composed by dark matter, the asymmetry between ordinary matter and anti-matter, ...). Many extensions to the SM or new theories try to address these issues and are investigated by physics researchers using particle colliders.

The Large Hadron Collider (LHC) is the largest proton-proton collider ever built and is situated in the Cern Laboratories in Geneva (Switzerland). It collides bunches of protons at high energy and delivers data to four experiments including the Compact Muon Solenoid (CMS). I'm part of this collaboration since 2014. The Compact Muon Solenoid is, together with ATLAS, one of the two multipurpose experiments designed to do accurate SM measurements and to investigate new physics in many final states.

The first data taking period (called Run1) of LHC lasted from 2010 until 2013, at the energy in the centre of mass ($\sqrt{s}$) of 7/8 TeV. After a shutdown of 2 years, it has been restarted again in March 2015 (Run2) at $\sqrt{s}$=13 TeV. In 2015 the LHC has delivered data corresponding to $\sim$ 4 fb^{-1} of integrated luminosity. Currently the machine it's off to permit technical interventions to both the accelerator and the experiments. It will restart again in April 2016. In the next two years LHC is expected to deliver about 100 fb^{-1}. Thanks to the high energy and higher integrated luminosity it will be possible to explore new energy regions never investigated before, whitin the timescale of my Ph.D. thesis.

Diboson resonance search

Many theories beyond the SM predict the existence of massive particle at the TeV scale that decays into pairs of SM bosons. The bosons coming from the massive particle can be W, Z, H or γ. One of the main advantages is the clean experimental signature thanks to the known properties and decay kinematics of the SM bosons.

One of the most interesting channels is HW $\rightarrow$ bb + lν. It's importance is related to the Run1 result of the analysis carried by CMS where a 2σ excess, compatible with a $\sim$2 TeV resonance mass, has been observed. Similar deviations in the same mass region have been observed also in other diboson final states. This particular decay channel has a large 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.

Another interesting diboson final state is related to the latest LHC results in Run2.

In December 2015, both CMS and ATLAS have found hints of an excess in the diphoton invariant mass spectrum with a local significance of $\sim 3\sigma$, compatible with a resonance mass of 750 GeV. More data, to be collected in 2016, will be needed to confirm this excess. In parallel, it is interesting to investigate this mass region with other decay channels. The $Z\gamma$ final states is one of the most appealing as in many theory models particles decaying into photons can also couple to Z bosons. The hadronic final state ($Z\gamma \rightarrow qq + \gamma$) has never been studied at the LHC and its sensitivity is expected to be roughly comparable with the leptonic one ($Z\gamma \rightarrow$ ll + γ, where l indicates electrons, muons or taus).

Ph.D. activity and plan

The two final states considered (HW $\rightarrow$ bb + lν and Z$\gamma \rightarrow$ qq + γ) contain both electromagnetic particles (electrons from the W decay or the γ) and jets (from the hadronic H and Z decays) which need to be measured very precisely.
Electrons and photons are detected in CMS by the Electromagnetic Calorimeter (ECAL). It is an homogeneous crystal calorimeter, made up of about 75000 lead tungstate ($PbWO_4$) crystals, aiming to reach an excellent energy resolution for the reconstruction of electromagnetic particles. To obtain the signal from particle interactions, each crystal is coupled to a photodetector. During my first Ph.D. year, I've been involved in the monitoring and calibration of the High Voltage (HV) system (which powers the barrel region of the calorimeter) to maintain each HV channel stable in time, granting a good energy resolution of the detector. As an additional task, I've implemented a software capable of communicating with the HV boards that reduces many operations that were done manually and that now are completely automatic. The signal coming from these crystals must be synchronized in order to guarantee the best performance in term of energy reconstruction and background mitigation. I have also worked on the timing inter-calibration of the crystals to improve this synchronization using samples of Minimum Bias events. The resulting timing resolution is better than 400 ps.
The other object used for these searches is the jet, which is a cluster of particles created from the hadronization of quarks and gluons that are produced during proton-proton collisions. For resonances with mass at the TeV scale, the momentum of bosons from the resonance decay greatly exceeds their rest mass. Therefore the boson decay products are emitted with a small angular separation in the laboratory reference frame. The identification of an energetic boson decaying into a pair of very collimated quarks (such as H $\rightarrow$ bb or Z $\rightarrow$ qq), thus resulting in a single massive jet, is an experimental challenge for the final states considered. It relies on boson tagging techniques which use the jet mass or other quantities which are developed to discriminate the dipolar structure of an hadronic boson decay from a jet created by the hadronization of a single quark/gluon. These variables need to be properly calibrated using control samples of $t\bar{t}$ events.
During the firsts months of 2016 I will continue the detector duties such as the HV calibration, whose new software is going to be used for the first time in February 2016, and the timing studies, which must always be monitored to assure the good

quality of data recorded by ECAL. The analysis work will start with the study of the jet substructure using a pure sample of energetic W bosons decaying into hadrons, which are present in $\mathrm{t\bar{t}}$ events. The thesis will continue with the search in one of the diboson channels described above and it will conclude with the publication of these results using the full dataset that will be collected in the next two years.