Mattia Lizzo PhD Research Project

Abstract My PhD research project focuses on data analysis within the CMS experiment. The main goal will be the search for the pure electroweak Vector Boson Scattering (VBS) process in the W^+W^- final state, combining the RunII data sets collected by CMS from 2016 to 2018. A special case of this mechanism is the s-channel Vector Boson Fusion (VBF) Higgs production mode, which I studied and analysed for my Master degree thesis [1]. Hence, this project will be the natural continuation of my previous work, and I will exploit the knowledge acquired in multivariate analysis techniques for an innovative approach to VBS. Future plans for VBS foresee the inclusion of data from the RunIII, which will start in 2021 and last until 2023. Therefore, I will participate and contribute to the data taking, this phase being essential to reach the sought 5σ-significance and claim the discovery. On a larger time scale, my aim will also be to perform a feasibility study in the HL-LHC scenario, where the pileup increase will be one of the major experimental challenges. In particular, I will focus on the new MIP (Minimum Ionizing Particle) Timing Detector (MTD), simulating the benefits that this upgrade will bring to the VBS $\rightarrow W^+W^-$ measurement.

Motivation The interest in studying the VBS process arises for several reasons [2]. First of all, the divergence of its cross section in the high energy limit is prevented by the presence of the Higgs boson, which enables cancellations between Feynman amplitudes involving quartic gauge boson interactions and preserving the SM unitarity. Besides, VBS represents an excellent probe to evaluate the effects of the spontaneous breaking of electroweak symmetry, being deeply related to the nature of W and Z bosons. Moreover, physics models beyond the SM predict the existence of anomalous quartic gauge couplings or additional resonances through the modification of the Higgs sector: an excess of VBS events with respect to SM expectations could be the evidence of such theories.

Analysis strategy Among the various processes that contribute to the VBS mechanism, I will consider the pure electroweak $VV \rightarrow W^+W^-$ scattering in which both W bosons decay to leptons. The final state is characterized by the presence of two jets emitted by the incoming interacting partons, and their peculiar kinematic topology will be exploited to recognize the signal. Indeed, one of the major challenges of the analysis will be to suppress $t\bar{t} \rightarrow b\bar{b}W^+W^-$ events, where the two b-jets are identified through dedicated algorithms. However, the high cross section and the non-negligible b-jet mistagging rate render $t\bar{t}$ pair production the dominant background, followed by higher-order diboson and Drell-Yan processes, which complicate the measurement. In order to deal with all these features, I will employ multivariate analysis techniques based on machine learning algorithms, since a standard approach could be insufficient to separate the signal from backgrounds. This task is perfectly suited to my experience, being part of my Master thesis work, where I tackled the VBF analysis with a similar strategy.

The LHC and CMS time schedule Up to now, CMS has collected about 170 fb^{-1} of p-p collisions data at energies between 7 and 13 TeV. These data sets have already provided extraordinary results, leading to the discovery of the Higgs boson in 2012. Still, they are currently used to carry out many different studies in order to test the Standard Model (SM) predictions. In 2021 LHC is going to restart operations after two years of shutdown and the overall integrated luminosity is expected to reach ~ 300 fb^{-1} by 2023. During this period, the energy could be increased up to 14 TeV, further enhancing the possibilities to observe elusive processes, such as VBS. The following High Luminosity phase (HL-LHC, CMS Phase-2), starting in 2026 until 2039, will allow to gather up to 3000-4000 fb^{-1} of integrated luminosity [3]. This will be crucial to conduct very high precision measurements, since they most benefit from the increase in statistics, determining a fundamental step towards the full comprehension of the physics at the TeV energy scale.

Simulation based studies on MTD To accomplish these goals, the CMS experiment will be upgraded and a timing detector will be installed between the silicon tracker and the electromagnetic calorimeter [4]. This new system will allow CMS to cope with the challenging environment due to the huge track density resulting from p-p collisions at high luminosity. During the HL-LHC phase, it is estimated that an average of 200 pileup collisions per beam crossing will be produced and the spatial overlap of tracks and energy deposits will spoil the reconstruction of many physics observables. The MTD is designed to assign a time stamp to each track with an estimated resolution of about 20-30 ps, improving the capability to distinguish pileup vertices. In particular, the MTD will reduce the probability of merging two different interaction vertices from 15% to 1% and, therefore, suppress the contribution of pileup jets. Moreover, by updating b-jet algorithms to be aware of timing information from the MTD, the number of spurious reconstructed secondary vertices is further diminished by roughly 30%. The VBS analysis deeply relies on the detectors' performances in b-jet identification, being that $t\bar{t}$ pair production is the main background: my aim will be to study the response of the MTD through simulations, to evaluate its positive impact on the VBS $\rightarrow W^+W^-$ measurement.

Project timeline During my first PhD year I will focus on the development and optimization of the multivariate analysis for the VBS process, publish the RunII's measurements and prepare the RunIII data taking. In 2021 I will actively collaborate for the acquisition of RunIII data and study the MTD simulation for HL-LHC. Finally, in the third year I will analyse the available data collected during RunIII, in order to get preliminary results and, in parallel, work to my PhD thesis.

References

[1] M. Lizzo, "Study of the Vector Boson Fusion Higgs production mechanism in the $H \rightarrow WW \rightarrow 2\ell 2\nu$ decay channel in proton-proton collisions at 13 TeV with the CMS detector", Master Degree Thesis (2019).

[2] CMS Collaboration, "Observation of electroweak production of same-sign W boson pairs in the two jet and two same-sign lepton final state in proton-proton collisions at 13 TeV", In: *Physical Review Letters*, `https://arxiv.org/pdf/1709.05822.pdf` (2018).

[3] CMS Collaboration, "Technical proposal for the Phase-II upgrade of the Compact Muon Solenoid", CERN-LHCC-2015-10 / LHCC-P-008 / CMS-TDR-15-02, `https://cds.cern.ch/record/2020886/files/LHCC-P-008.pdf` (2015).

[4] CMS Collaboration, "Technical proposal for a MIP Timing Detector in the CMS experiment Phase 2 upgrade", CERN-LHCC-2017-027 / LHCC-P-009, `https://cds.cern.ch/record/2296612/files/LHCC-P-009.pdf` (2018).