

SEARCH FOR RESONANT DOUBLE HIGGS PRODUCTION WITH bbZZ  
DECAYS IN THE  $b\bar{b}\ell\ell\nu\bar{\nu}$  FINAL STATE IN pp COLLISIONS AT  $\sqrt{s} = 13$  TeV

by

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Since the discovery of the Higgs boson in 2012 by the ATLAS and CMS experiments, most of the quantum mechanical properties that describe the long-awaited Higgs boson have been measured. Due to the outstanding work of the LHC, over a hundred of  $fb^{-1}$  of data have been delivered to both experiments. Finally, it became sensible for analyses teams to start working with a very low cross section processes, which made it possible to observe rare decay modes of the Higgs boson, e.g., a recent success in observing ttH and VHbb processes. One of the main remaining untouched topics is a double Higgs boson production. However, additional hundred of  $fb^{-1}$  per year from the HL-LHC will not necessarily help us much with the SM double Higgs physics, the process may remain unseen even in the most optimistic scenarios. The solution is to work in parallel on new reconstruction and signal extraction methods as well as new analysis techniques to improve the sensitivity of measurements. This thesis is about both approaches: we have used the largest available dataset at the time the analysis has been performed and developed/used the most novel analysis methods. One of such methods is the new electron identification algorithm that we have developed at the CMS electron identification group, to which I have had a privilege to contribute during several years of my stay at CERN.

The majority of this thesis is devoted to techniques for the first search at the LHC for the double Higgs boson production mediated by a heavy narrow-width resonance

in the  $b\bar{b}ZZ$  channel:  $X \rightarrow HH \rightarrow b\bar{b}ZZ^* \rightarrow b\bar{b}\ell\ell\nu\bar{\nu}$ . The measurement searches for a resonant production of a Higgs boson pair in the range of masses of the resonant parent particle from 250 to 1000 GeV using  $35.9\text{ }fb^{-1}$  of data taken in 2016 at 13 TeV. Two spin scenarios of the resonance are considered: spin 0 and spin 2. In the absence of the evidence of the resonant double Higgs boson production from the previous searches, we proceed with setting the upper confidence limits.

“... a place for a smart quote!”

*Lenin, 1922.*

## ACKNOWLEDGMENTS

This will be a longgggg list!

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## CHAPTER 1

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### Conclusions

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This thesis is about the search for the double Higgs boson production mediated by the intermediate KK graviton and separately by the radion heavy resonances in the  $bbZZ$  channel: one of the Higgs bosons decays to two  $q_b$  quarks while the other decays to a pair of Zbosons which, in turn, decay to a pair of neutrinos and a pair of electrons or muons. For this measurement we used 2016 data set with the integrated luminosity of  $35.9 fb^{-1}$  collected by the CMS experiment at the LHC in the proton-proton collisions at  $\sqrt{s} = 13$  TeV.

No statistically significant deviations from the SM predictions for background processes have been observed, and 95% upper confidence limits are reported for production cross section of a KK graviton/radion times the branching fraction of the subsequent decay into an HH system. The limits are derived for resonance masses in the 250 GeV to 1 TeV range.

This analysis became public in November 2018 [?]. Now, according to the CMS Physics Coordination, CMS wants to see a combination of this analysis with the other  $bbZZ$  analysis, which is focused on the 2 b jets, 2 leptons, 2 jets signature. Currents plans are to produce a paper for the Physical Review D (PRD), where we will report the best limits for all available  $bbZZ$  channels. Of course, prior to the grand  $bbZZ$  merge, each analysis combines the data from both dimuon and dielectron channels.

The mass range to be covered in the combined measurement is also from 250 GeV to 1000 GeV.

## **CERN guide, S'Cool Lab teacher, Finance Club admin, Boxing Club coach**

It has been a great pleasure to stay at CERN for four years. From the bottom of my heart I want to thank my adviser and my HEP group for such an opportunity. I have exploited all the possible areas of science, outreach, fun, and joy available at CERN. Well, almost all, and I know it is ridiculous, but I have not tried skiing...

I have been an official CERN guide, giving people tours to Antimatter Decelerator, ATLAS control room, The Low Energy Ion Ring complex, Proton Synchrotron, LHC control room, Data Centre, The SM18 facility (a world leading magnet test facility for testing magnets and instrumentation at low temperature and high currents), The Alpha Magnetic Spectrometer control room. Audience ranged from middle school kids to emeritus professors of science.

Also I have been a teacher at the S'Cool Lab where high school students have a chance to come to CERN and build at this "cool" laboratory a real experimental setup and then conduct the experiment on their own.

For more than a year I have been an administrative officer at the CERN Finance Club. I have been inviting top professionals from the finance and fintech companies to give talks at our club, I have started the quant group at the club, and have been the first to optimise our portfolio of stocks using Monte Carlo methods and also later with the minimisation technique. needless to say, that I learnt all those tools in High Energy Physics!

Last but not least, my friends from the CERN Powerlifting club introduced me to the Boxing Club. The rest is a history. I have been training people with the goal to improve their health. As a side effect, some picked up self-defence, others had fun and found themselves truly addicted to this combination of the hard work and laughter, and a few even became very much into the world of the intelligent boxing, which is about strategy and outworking the opponent.



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