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In Prague, September 7, 2025

Opponent's assessment of doctoral thesis

submitted to Faculty of Mathematics and Physics, Charles University

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Title:	**Search for New Phenomena using the Production of Four Top Quarks at the Large Hadron Collider**
Year of submission:	**2025**
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The doctoral thesis presents analysis of proto-proton interactions at the Large Hadron Collider (LHC) collected by the ATLAS detector. In particular, the main work performed is the search for New Phenomena in collision events containing four top-quarks (two $t\bar{t}$ pairs). Top quarks decay predominantly in b-quarks and W-bosons, with W decaying either leptonicaly or hadronically. The analysis focuses on final states contains either 1 lepton (1L) or 2 opposite side leptons (2LOS) from the W-decays, and multiple jets.

Thesis itself is composed of Introduction, 4 chapters, Summary and Conclusion, and 5 appendixes. The $t\bar{t}t\bar{t}$ analysis is carried out within a larger analysis team, however, the author's contributions are clearly described in the introductory sections. After brief motivation in the Introduction section, a broader description of the Standard Model of particles and their interactions (SM) follows, with detailed sub-sections on top-quark properties and production, and processes leading to the four-top final state, including two beyond-SM scenarios tested in the data analysis.

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The LHC and collision parameters, and the ATLAS detector with its sub-detectors, are described in the second chapter. The chapter includes also the trigger and data acquisition system, and author's technical contribution to ATLAS Upgrade project, the production database for the tracking sub-system (ITk).

The remaining chapters are devoted to the ATLAS four-top analysis in the 1L and 2LOS channels. The third chapter discusses in details all aspects of the analysis. Starts with the description of the used data and relevant physics processes and related Monte Carlo (MC) samples, event selection and categorization, signal and background estimates and corrections (reweighting to data), and the usage of MVA techniques to discriminate signal from backgrounds. Follows list of systematic uncertainties, and a broad description of the statistical analysis based on profile likelihood estimator, cross-checks before and after unblinding the signal regions, and finally presenting the results: observed significances, analysis of final systematics, and the limits on the production and properties of the test beyond-SM physics models. The last chapter before the summary and conclusion is devoted to selected post-validations, trying alternative approaches to simulations or event classification, or analyzing potentially unhealthy patterns, to which studies the author has contributed.

For the formal part, there are quite some typos and other errors (e.g wrong label of Figure 2.6, unreferenced Figure 4.25), but understandable given the length of the thesis (and usual time pressure). I also found several factual imperfections (e.g. wrong Pixel's pixel size, Run 3 years range), or in the references would prefer using the original sources instead of materials as proceedings (if possible), but again not degrading the quality of the work done.

From the present work, the author has made clearly significant contribution to the four-top analysis within the international analysis team. The studies were documented within the paper internal documentation. The author was dealing with the analysis at every stage up to collaboration review and approval (being selected as the speaker at an approval meeting) and submitting the results into HEPData repository. Results were also presented as several conferences and published, beside the ATLAS paper itself, in the conference proceedings.

I have several questions listed on the next page; however, **I am confident that the thesis is of high quality. Upon successful defense, I recommend that the thesis be accepted as a doctoral dissertation and that Chainika Chauhan be awarded the degree of Ph.D.**

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Questions regarding the defense of the thesis:

1. Concerning the categorization of events in Figure 3.5, the signal region covers also the 9(7)-jets bin in the 1L(2LOS) channel, while from the logic of the channel, there should be 10(8) jets. Is the one jet missing because of small energy of rather because of jet merging (or boosted W-decay)?

2. Are the p_{T} cuts in selection of leptons in Section 3.2 tuned to this analysis, or are they just following the trigger thresholds or the electron/muon quality criterion? Is there no $E_{\mathrm{T}}^{\mathrm{miss}}$ cut?

3. As for the NN-based kinematic reweighting of the $t\bar{t}$+jets MC, it is later mentioned that it should well model also the correlations between the input variables. Has that been explicitly checked? Also, the Figures 3.7 suggest that the reweighting corrections are within the total uncertainty in the pre-fit background. So the question is: is the reweighting needed? Has it really a significant impact on the analysis?

4. Pruning of systematics: is there any estimate how much the total systematics could get reduced by not including those least significant ones in the fit? The 0.5% cut-off sounds reasonably small, but as it removes 80% of the systematic variations, the total impact might be non-significant(?).

5. When comparing the alternative approaches for signal separation (GNN versus BDT), is the ranking (or the order) of the features in tables 3.8 and 4.1 similar, or are there any indications that GNN gives more importance to other variables than BDT?

6. In the summary and conclusions, general ideas about improvements at HL-LHC are mentioned. Are there known any projections of the sensitivity of the $t\bar{t}t\bar{t}$ analyses at HL-LHC?

In Prague September 7, 2025 doc. RNDr. Pavel Řezníček, Ph.D.