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Reviewer report on PhD thesis "Ina Carli: Angular analysis of the $B^0 \to K^*\mu^+\mu^-$ decay with the ATLAS detector"

The thesis of Ina Carli named "Angular analysis of the $B^0 \to K^*\mu^+\mu^-$ decay with the ATLAS detector" consists of two main parts discussing particular physics measurement using data collected by ATLAS experiment and technical contributions to the running of ATLAS experiment and preparing upgrades for the future. The physics analysis presents the measurement of the angular observables in the $B^0 \to K^*\mu^+\mu^-$ decay, which is a topical and important measurement. In the technical contributions, the thesis describes contributions to work on upcoming tracker upgrade for ATLAS and background monitoring in the current detector during so-called Run 1 of LHC data taking. While I critically evaluate both parts of the thesis, given that my expertise lies in data analysis of heavy flavour decays I will put more emphasis on the corresponding part of the thesis.

The decay $B^0 \to K^*\mu^+\mu^-$ is rare flavour changing neutral current decay governed at the quark level by the $b \to sl^+l^-$ transition. The measurements of the properties of this and similar decays are currently the hot topic in the quark flavour physics community as such decays provide excellent sensitivity to new physics not described by the Standard Model of particle physics. In addition, there are few recent measurements which show some discrepancy between experiment and theory predictions. Most notable ones are tests of lepton flavour universality where comparison of rates of rates between decays with dimuon and positron-electron pairs is made in decays $B^0 \to K^*l^+l^-$ and $B^+ \to K^+l^+l^-$ (JHEP 08 (2017) 055 and PRL 113, 151601 (2014)) and measurement of the angular observables in $B^0 \to K^*\mu^+\mu^-$ decays (JHEP 02 (2016) 104). The wide interest in these measurements is supported by a large number of citations these measurements attracted (304, 709 and 394 respectively). The presented work describes details of second of these measurements using data collected by the ATLAS experiment and provides an important contribution towards establishing whether discrepancies seen before are indeed due to the new physics. In a way, if somebody would ask me what measurement in the quark flavour physics sector should do as first, this would be likely the one I would suggest.

The measurement is performed using unbinned maximum likelihood fit to angular distributions in the observed decays. Several angular observables are extracted. Amongst them, most discussed is P_5' which showed some discrepancy with the Standard model in LHCb measurement (JHEP 02 (2016) 104). The analysis was performed in the blind mode with fixing analysis without looking to the data, which is common in this type of measurements. The precision of the obtained result is not greatest but it does not decrease the value of the result. My general feeling is that part of the reason for rather large uncertainties is due to the unexpected background observed, nature of which makes it rather hard to work out before looking to data.

Given my deep interest in the topic, I have several questions and some comments:

- With hindsight that the precision of the measurement is not very good, it is clear that using more data would be beneficial. Unfortunately, the thesis does not provide any motivation to restrict the analysis to 2012 data only. For sure 2011 data must have been available as well as some of the Run 2 data and including those would make measurement more precise.
- Thesis gives the correct full angular expression for the decay, but from some reason restricts measurement to the subset of observables. This does not seem necessary and remaining observables could be measured as well, so what was the motivation behind this restriction?
- Another restriction which is unclear is to perform measurement only at low dimuon invariant mass squared, q^2. While q^2 region used is certainly hugely interesting, motivation to avoid high q^2 region is not clear.
- Description of selection is lacking some useful details. Particularly it is not clear how the decision on selection requirements was made.
- Description of simulated samples are not clear and for several of them, I could not identify what exactly has been simulated.
- In several places thesis talks about decay $\Lambda_b \to \Lambda(pK^-)\mu^+\mu^-$ but I could not work out through the whole thesis what exactly this is.
- Dealing with the angular distribution of misreconstructed B^0 candidates is one of the important points. The thesis suggests that actual angles of those events are very close to be the same as for correctly reconstructed decays just being in different quadrants. This point is not obvious and it would be useful if this would be supported by some plots showing it is indeed the case. I was not fully convinced here given my prior experience.
- The analysis assumes that angular distribution of combinatorial background, as well as angular efficiency, factorize. I would expect to see some evaluation of how good such an assumption is. Also, there are methods, which would allow to include correlations and in principle should work here.
- It would be useful if angular resolution and q^2 resolution could be specified. Without knowing the actual resolution, it is impossible to judge, whether it can be neglected completely in the analysis, whether one can ignore it but assign systematic uncertainty or whether it needs to be treated fully in the analysis.
- I was somehow surprised with the smallness of misreconstructed backgrounds, particularly one due $B_s \to \phi\mu^+\mu^-$ decays. It would be useful to see some more details on how it was evaluated.
- Description of how event-by-event mass resolutions were treated lacks details. I would like to see more rigorous explanation of what is done. Another question here is how

much it actually helps to improve statistical uncertainties of the measurement.

- Background observed after unblinding the data had a clearly significant effect on the result. There is extensive discussion what this could be but for somebody outside ATLAS experiment, it is not easy to think about it as there is no information on muon misidentification. From the discussion, I would suspect that the background is due to the $B \to DX$ decays but it is not fully clear what exactly in this class was really investigated. Especially I would suggest to check whether doubly semileptonic decays (where both B and D decays semileptonically) could be the cause. I'm also somewhat surprised that there is no attempt to use generator level sample to get the idea what kind of decays could contribute. Effects of misreconstruction or partial reconstruction would usually be large enough that even generator level study could give a good idea whether some source can be background or not.
- It is not clear, which of the several fits is used as default result for longitudinal fraction F_L.
- It would increase confidence in the result of the result of angular analysis on $B^0 \to J/\psi K^*$ decay would be presented even if that part of the analysis was done by a different member of the team.

In chapter 5, description of ATLAS SCT operation, its limitations for the future and some of the work towards building new detector ITk. The part on the SCT operation is useful as documentation of some operational aspects but it is not fully obvious what part is work of the author and which part summarises collective work of the SCT operation group. It is clearly expressed why current tracker will need replacement during LS3 and what are plans for it. The final part of the chapter describes work on setting up the test stand in Prague to be used for ITk developments. Unfortunately for somebody who is not familiar with ATLAS upgrade plans, it is difficult to understand how this work is beneficial to the project. Some description of how described work fits into overall ATLAS upgrade plans and conclusion of what was achieved would be helpful.

Finally, chapter 6 describes work on monitoring of non-collision background at the ATLAS experiment. The non-collision background can have significant effects on the ability to analyse data and there detailed monitoring is a necessary step in understanding and mitigating it. In this view, presented work provides useful insight and built up tools which allow to identify the bunch crossings in which larger background occurs. This type of information and ability to discriminate between collision bunch crossings with and without a high non-collision background will become important in future as LHC collider increases its luminosity. The main comment to this chapter is that it is lacking some conclusion and especially I would be interested to understand how the ability to tag bunch crossing with high non-collision background was used in ATLAS experiment.

The thesis of Ina Carli presents important measurement which contributes to our general understanding of the decays governed by the $b \to sl^+l^-$ decays. This is supported by the fact that journal publication of this analysis (JHEP 10 (2018) 047) is recognised and already attracted 12 citations by now. The described analysis is sound and correct. Its description is clear in most places and allowed a detailed understanding of the work performed. The technical parts provide details on the useful contributions to the ATLAS experiment. While those parts are might not bring too much of new results, it is an important contribution for current and future physics measurements at ATLAS experiment. The questions and comments above do not decrease the value of the presented work, on the contrary, many of them stem from my personal deep interest in the presented measurement. Comparing the presented thesis to others I had a chance to supervise or review in several countries I find thesis of Ina Carli of comparable quality. Given all this, I believe that the thesis demonstrates that Ina Carli is capable of independent work and thus I recommend to accept it and to award PhD degree.

Coventry, UK, December 4, 2018 M. Kreps