Opponent's Report on the Dissertation

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Title: **Radiation hardness and performance of the hadron calorimeter designed for Projectile Spectator Detection in the framework of international collaboration CBM@FAIR**

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Vasily Mikhaylov, as a member of the international CBM@FAIR experiment, performed in his doctoral thesis a very detailed and comprehensive study of the radiation hardness one of the parts of CMB detector, the Projectile Spectator Detector (PSD). In general, the thesis might be divided to three parts, even if they are linked together. First part starts with the general overview on radiation damage of detectors used in the particle physics. Although, the main topic of this part is a (truly) extensive review of radiation hardness of calorimeter, where author goes through scintillators, optical fibers, semiconductors, silicon sensors, finishing with the silicon photomultipliers (SiPM), which are main concern through the whole work of his. At the end, he describes the CMB experiment and the design of the PDS detector. Second, even bigger part, is the own experimental work done by the author. He starts with the irradiation of PSD scintillators at the NPI Řež cyclotron facility, then continues with irradiation of different types of SiPMs at the same facility, and finally moves on to the study of radiation hardness of these SiPMs at the CERN SPS beamlines. He performed many kinds of SiPMs' characteristics measurements non-irradiated and irradiated with various fluences and their effects on breakdown voltage, quenching resistor, pixel capacitance, gain, dark currents, LED signal response, single photo-electron resolution, signal-to-noise ratio comparison, etc. Finally, the last part is devoted student's study of the simulations of PSD response on the different generators. At the same end of the thesis author concludes all his work and adds many recommendations and suggestions not only for 'his' experiment but for other future experimental studies and detectors.

Timeliness:
I think the submitted thesis is live and topical to the current situation in the particle experimental physics and in searching to solve issues given by big experiments as it is the CMB at FAIR. The issue of the radiation hardness of different parts of detectors is crucial, and the main topic of the thesis, the measurement of the SiPMs is one of the challenging and rapidly evolving.

Methods and systematics:
The student shows in the entire thesis very good access how to describe nowadays situation with the compressive study of available literature, to set up and perform experiments, to use experimental data, to make results from them and to conclude and summarize whole work. Although, here I have some a bit critical comments, see my notes bellow.

Thesis goals:
I may say that the goals given to the student's study are very well mirrored and matched in his thesis, even I would say the results are exceeded the goals. Certainly, the results might be very useful to solve some issues within the experiment. This also support number of the papers where the student is a main author or co-author and number of the given presentations.

Scientific results and benefits:
Clearly, in the work there a lot of useful results, I will not comment on them. They may be used not only in his own experiment, but also by other experiments and to be as a very reasonable starting point for other studies.

Notes and comments:

- My general comment on this thesis is its length of the text. It might be my point of view to have to review, however I think even for a common reader it is too long. In some parts I thought I was reading a school book or script for the students (chapter 2 and 3). I understand that a thesis must include some theoretical basics, but to cover everything it is not aim of a dissertation thesis. When I somewhere started to read "a short overview of …", I was sure it would be awaiting many pages of words. Many times, what is called 'summary' might be a full review. In other part of the thesis I thought I was studying a programming manual (chapter 7.3). I am sure the author is proud of it; however, a reader is not eager to go through. Of course, if I want to measure it is nice piece of work.
- In principle it would be rational to even omit the last chapter about the simulations.
- Fig 1.1 shows a 3-dimensional picture.
- 'Annealing' process should be explained and discussed earlier than I found.
- In tab 6.3 in the column for the relative deviations of the foil fluences, pluses and minuses would help to better read it.
- A mismatch between referring to Fig 8.14 and 8.15 in the text on page 219.
- I have not found a nowadays timeline for the experiment anywhere in the text.

Questions and discussions:

- What is a timeline for a tuning and fixing of the final design of the detectors, especially PDS modules for an assembly? When will be taken a decision on choosing final SiPM candidates if not done?
- Why will experiment be taking data only (very) few months in a year?
- Was it anytime in mind to build any 'in-situ' calibration system to the PSD? I think they are even online correcting calibration systems (temperatures versus voltage versus gain).
- How will be affected the physics performance by cutting a bigger hole in the center of the PDS? It is clear it will help to lower the radiation there, but what about resolution or acceptance of the main quantities?
- What changes in results might happen if you used for radiation instead of plastic scintillator of the size of 0.4x2x2cm3 the actual ones to be used in the PSD (chap 5.)?
- In the setup at NPI for the SIPM radiation measurements was used UV LED at 400nm. I think many kinds of the used SiPMs much vary in response (it is very low) on the short wavelength light due to different their PDEs? Might be using different light 'color' any effect on the showed results?

Regardless of my criticisms of the thesis length, and in advance, assuming to positively answer my questions in a discussion, I asset and recommend the submitted dissertation thesis hereby:

The Vasily Mikhaylov's work demonstrate author's assumptions to graduate with PhD.

In Prague, May 25, 2021

Jaroslav Zálešák