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Review of the PhD Thesis

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Title: **Read-out and online processing for the Forward Tracker in HADES and PANDA**

Supervisor: **prof. dr hab. Piotr Salabura**

Co-supervisor: **Grzegorz Korcyl**

1. General information about the thesis

The reviewed thesis was written by Mr Akshay Malige, the PhD student at Faculty of Physics, Astronomy and Applied Computer Science in Jagiellonian University. The scope of the thesis is related to PANDA and HADES experiments at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany. The main aim of the reviewed thesis is to develop and verify the methods necessary to achieve the required energy and position resolution in the Forward Tracker (FT) detector in the abovementioned experiments. In Chapter 1 (Introduction), the author has clearly formulated the goals of his work and defined the tasks necessary to fulfill them.

The thesis is written in English. The main part is 106 pages long and is divided into six chapters.

The main part is preceded by auxiliary sections, including abstracts, acknowledgments, collaboration contribution statement, table of contents, list of figures, list of tables, and list of abbreviations. The main part is followed by appendices describing the technical details of the design and procedures and the bibliography. The whole thesis is well organized.

The first chapter is the Introduction. The sixth chapter is Summary and Outlook. Chapters two to five are related to individual problems related to the work done in the thesis.

Chapter two describes the environment in which the work was done. It starts with a description of the FAIR facility, then describes the HADES and PANDA experiments, then the straw tube detector used in the forward tracker, and finally, the readout and the data acquisition systems created for those experiments.

Chapter three describes the work associated with preparing the Forward Tracker (FT) readout system. It starts with a description of the properties of the straw tubes and the produced signal. Then it formulates the requirements for the frontend electronics, properties of the shaped signal, and the method of its digitization based on Time Over Threshold (TOT) approach. Next, it describes the PASTTREC readout ASIC designed for FT, its metrological properties, and the qualification methods. This chapter also describes the significant original methodological contribution of the author – the noise profile scan method used to determine the baseline level of individual channels.

Chapter four describes the tests of the detector and the associated readout system. It provides a detailed description of the preparation of the test setup, applied analysis methods, and created analysis software. The solutions described in this chapter were based on previous development. However, the author has performed significant research work analyzing the data and formulating the operating conditions for the FT detector. The new effect considered here by the author is the influence of the straw deformations on detector parameters. The obtained results enable the detection of such deformations.

Chapter five describes the original FPGA-implemented real-time data processing framework developed by the author. The author has defined possible operating modes of the framework and proposed its general, modular pipelined structure. The author has also developed example base modules like geometry parser, first- and second-stage filters, and the tracking engine. The author utilized the High-Level Synthesis (HLS) based approach to enable easy implementation and modification of processing algorithms. The proposed firmware was successfully implemented in the ZCU102 prototype board and tested with the real detector. The tests have shown the correct operation and usefulness of the solution. The author has also formulated the possibilities for further development.

In chapter six, the author has summarized the main achievements of the thesis, related to the identified properties of the readout chain and providing possibilities of optimization of the operating conditions of the detector. The author has also described the perspectives for modifications of the Forward Tracker for the PANDA high-luminosity mode.

2. Analysis of sources

The author places his work in a broad context containing detailed information about the PANDA and HADES experiments, the detection methods, and the detector's properties.

This description is based on properly referenced sources. The bibliography of the dissertation contains 35 positions. Half of them are the articles from high-impact journals. Five of them are the Technical Design Reports related to the related experiments. Seven of them are websites. Other bibliography positions are the PhD theses, conference proceedings, collaboration materials, and one book. Generally, the sources are well selected.

However, one significant position is lacking in the bibliography. This is the publication in IEEE Transaction on Nuclear Science, “Real-Time Data Processing Pipeline for Trigger Readout Board-Based Data Acquisition Systems” (DOI: 10.1109/TNS.2022.3186157), where Mr. Malige is the first author. It is especially important, as a significant part of Chapter five is identical to this article. That publication is mentioned at the end of the Collaboration Contribution statement but not included in the bibliography nor referenced in Chapter five.

The bibliography also has other editorial shortcomings. Positions 14 and 35 have no information about availability. Also, the bibliography information for positions 15, 25 and 33 does not allow to find them easily. Position 28 contains DOI (even twice) but lacks a title, authors, and journal.

3. Other remarks

I have a few minor editorial remarks:

1. Using italics for subscripts as normal words (not variables) impairs legibility. An example may be Equation 3.3.
2. There are some problems with fonts in Figure 3.6
3. Equations 4.1 and 4.2 define „r” as a function of „t”. However, in both equations the right side does not contain „t” as an independent variable.
4. In Figure 4.28, the scale of the Y-axis is not properly selected.

4. Questions to the author

As I read the thesis, some statements raised some doubts in me:

1. The noise profile scan method seems to be an improvement comparing to the S-curve scan. However, how is it sensitive to noise distribution? What if the noise RMS is significantly smaller than the baseline step? Is it possible?
2. The data rates listed in table 5.1 are relatively low. Wouldn’t it be justified from the economic point of view to use a smaller and cheaper FPGA but higher speed link and process the data in the computer system instead of FPGA?

5. Assessment of fulfillment of requirements for PhD dissertations

The thesis proves that Mr. Malige has deep theoretical knowledge related to High Energy Physics experiments, detector systems, readout systems, their development testing, and calibration.

The goals formulated by the author in Chapter 1 have been fulfilled.

The reviewed thesis proves that Mr. Malige has the ability to perform independent research work. He has done significant research work related to the preparation of the measurement setups, development of the tools for data acquisition and analysis, analysis of acquired data, and formulation of conclusions. He has created methods enabling the equalization of baseline positions and gain in the detector. His work resulted in the optimization of the operating conditions of the straw tube detectors, leading to the improvement of measurement results and an increase in the operational life of the detector.

In that sense, Mr Malige's dissertation is an original solution to the scientific problem.

Additionally, his thesis contains at least two strong innovative elements. The first is the noise profile scan method, which enables measurement of the baseline position and the noise level faster than the previous S-scan method. This method does not require an external pulse generator and therefore is better suited for characterizing of the PASTTREC chips in the final setup.

The second innovative element is the preparation of the concept and practical implementation of the hardware real-time data processing in FPGA.

All mentioned achievements are significant contributions to HADES and PANDA experiments and also to future experiments based on similar technology.

Therefore, I declare that the PhD thesis of Mr. Akshay Malige meets all formal and customary requirements for the doctoral dissertations, and I am applying for admission of Mr. Akshay Malige to the following stages of the PhD procedure.