Review for the defense of the doctoral thesis by Gábor Nyitrai: Particle physics detector development and application for muography

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1 Thesis

Gábor's work presents well-documented and evaluable results in muography, with significant hardware improvements to ensure stable operation of the detector and developments in data analysis. The engineering approach is evident in his work, the aim of the improvements is the usability of the measurement results, he has subordinated the necessary steps to this aim, he has been able to understand and use methodologies from several disciplines to achieve this goal. The group itself is unique in its successful use of gaseous detectors in muography, and he has made a significant contribution to the success of the group.

1.1 Introduction, Principles of Muography

After a short introduction, he gives a detailed overview of muography. Starting with the discovery of muons and their physical properties, there are illustrative examples of the advantages and disadvantages of the use of existing experimental physics detectors in muography. He explains the principles of measurement and possible backgrounds, and the solutions his group has found for suppression. He points out that detectors often have to be installed in difficult to access, humid places, which requires additional hardware improvements compared to the physical measurements used in a laboratory environment.

1.2 Gaseous detector developments for muography

The REGARD group has developed the CCC detector as an evolution of the traditional MWPCs for the ALICE detector VHMPID sub-detector. A good example of the benefits of physics research is that these innovative solutions have not remained within the framework of basic research, but have found their way into practical applications in volcano tomography, cave mapping and mining. Gergő has made significant developments in the assembly and stable operation of large surface area detectors that can be used well in muography, and the ideas and proven solutions have been provided by his group-level experience with CCC and other detectors. It is also clear that this group formed for basic research can provide a knowledge base that can meet industrial needs. The candidate has developed Advanced Multi-Wire Proportional Chambers and has developed several methodologies to improve and ensure stability, efficiency, taking into account that muography often requires several months or years measurements in non-ideal environments. He has developed and performed thorough tests on how efficiency varies with changes in gas composition, how 3D printed components -he designed to provide large surface geometric stability- appear in the measurement, and what the angular resolution of the detector is for given wire spacings. In this chapter, he describes the method he has developed to efficiently assemble large surface area detectors and the improvements he has made to produce detectors that are fit for muography. There is a very detailed and well theoretically based measurement of how to reduce the gas consumption of the detector so that the frequent replacement of gas bottle in the field is not necessary. This work has also been published in a first-authored paper.

The GEM (Gas Electron Multiplier) is a widely used but still a new detector technology mainly used in high energy physics. Experiments have developed their own calibration procedures to measure the parameters of the GEM layers -that are important to them to reach their physics goals- before installation. Gábor has further developed a calibration procedure, already existed before he joined to the REGARD group, in order to perform the quality assurance steps for as many types of GEM foils as possible. By improving almost all the hardware and software parts of the Leopard tester, he has achieved a very detailed map of the photoelectron yield and gain of several GEM foils with different thicknesses and coatings. I consider this an independent and significant contribution to the PhD degree.

1.3 Muographic imaging data evaluation

Although muograpy seems simple at first, it uses a lot of parameters that are still difficult to measure or estimate. Starting from the fact that the angular and energy spectrum of muons is not precisely described, there are different models, things such as the temperature, not only at the detector but also in the upper atmosphere, the solar wind, the type of tracking algorithm used at the detector, the exact geological data of the area, must be taken into account. These are listed in detail, and it can be seen that some sources of uncerainties are difficult to estimate. Gábor has prepared a software framework in which these errors can be minimised using the available data. Here, the candidate's extensive experience and willingness to learn is evident, as he was able to bring together in one framework the geological information, measurement methods and the boundary conditions arising from detector operation. In this chapter we get an overview of why existing methods of tomography cannot be used for muongraphy in one-to-one and he has developed his own models, which he has verified with measurements. This topic is diversified, and the candidate has developed and published it at a level appropriate for a PhD degree.

2 General remarks

The work of the group and the individual is difficult to separate in such complex projects, which can only be carried out by a group, and sometimes difficult to follow in the thesis, but can be clearly identified in the summary. I did not find any significant errors in the English, the text is well structured and comprehensible.

3 Questions

1. Can the scattering muography be used for large object tomography? If yes, under what conditions?
2. Page 15: when you are talking about "in some cases even up to 5 GeV", is it the muon or the parent particle? If it is the muon, since energy of the primary cosmic particle can be even 10^{20} eV, it can be even higher. In the real measurements what is the origins of these up to 5GeV muons?
3. The borehole detectors were mentioned, how can these small detectors be used for muography?
4. In the CCC your group used strips, why did you use pick-up wire plane in the AMWPC instead of these strips? What are the main innovations, developed by the CCC, you use in the AMWPC?
5. Page 24: what was the trigger conditions for this test? Did you optimize/reset/lower the signal condition to have trigger from the chamber 1, or 4/5 trigger condition solved this problem. Did you change the digital trigger threshold to have track point at the chamber 1, or the original threshold was used before and after the injection?
6. How the tracking algorithm determines the number the position and the width of the lead walls. Describe the tracking algorithm you used here.
7. In the paper: High Efficiency Gaseous Tracking Detector for Cosmic Muon Radiography, Fig 5 shows the signal amplitudes by 5/6 and 6/6 trigger conditions. The gauss shape of the peak at 5/6 trigger condition suggests one chamber is not working at all, because no signal is coming out, all I see is noise. What can be the reason? If a chamber gives a lower than average signal, this peak should have different shape.
8. Fig 3.36: the post-amplifier seems to be not CCC, can you create a scaled plot? If the bottom of the GEM is not grounded, how it changes the

parameters of this post-amplifiers? Did you used the field wires and strips (if it's a CCC) for validating the avalanche positions?

9. Fig 3.40: What was the exact configuration in this measurement? You mentioned it was above the detector, does it mean above the GEM foil?

10. Page 85: you are talking about the uncertainty of the ML-EM method. Is it the statistical or systematical uncertainty? Why can't we say anything about the uncertainty by this method?

11. Fig 4.10: What are the reasons of those artifacts? Do these shadow lines come from the method?

12. Fig 4.14: Are those lines anomalies or real lower density areas?

4 Summary

I accept this thesis as worthy of a PhD degree. My assessment: **summa cum laude**.

Debrecen, 2024.03.21.

Ujvári Balázs