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Review of the Doctoral Thesis *"Ultra-High Energy Cosmic Rays and Their Detection in Auger Project"* by Michael Prouza

To Whom It May Concern:

This is a review of the doctoral thesis "Ultra-High Energy Cosmic Rays and Their Detection in Auger Project" by Michael Prouza. The thesis work was performed in the context of the Pierre Auger Observatory, a new state-of-the-art detector for the highest energy cosmic rays currently under construction in Malargue, Argentina.

The review is organized as follows. I will first give some general comments on the thesis, followed by a more detailed review which will include some questions to the candidate. This will be followed by a summary statement and the recommendation that the candidate obtain his degree after a successful defense. I also include an appendix with a short list of minor inaccuracies that should be corrected in the final version.

## General remarks

First, some overall remarks. This is an unusual thesis in that the candidate has worked on a variety of different topics, all related to ultra high-energy cosmic rays and their detection. These topics cover almost the full range of this exciting field of physics, from more theoretical analyses of particle propagation in Galactic magnetic fields to experimental problems, most important the pointing accuracy of the Auger fluorescence telescopes. It also touches on very practical issues, for example the extension of the telescope's running time during moon light. Another major achievement is the building and operation of the FRAM telescope for atmospheric monitoring at the experiment's site in Argentina. All

these topics can be considered stand-alone thesis topics in their own right. That Michael Prouza worked on all of them is indeed very impressive.

These days, in particular in fields like particle physics, a thesis quite often describes mainly a single analysis, which is consequently presented in great detail. This thesis presents a different approach. Michael Prouza has worked on a number of projects covering software and hardware development, simulation, and data analysis. Consequently, he is not going to the same level of detail that could be expected from a student who has mainly worked on a single topic. Personally, I consider Prouza's approach the preferred one; his thesis shows considerable breadth, and I am therefore very happy with his work.

**Detailed review**

The most important impression I got from reading this thesis is that Michael Prouza has brought an astronomer's point of view to astroparticle physics. The topics he has worked on are diverse, but a common thread is the application of astronomical tools in an area that is still dominated by particle physicists. Most scientists on Auger (or any other collaboration in the field) have a particle physicist's background. Prouza's contribution is therefore quite unique; several of the topics he has worked on require solid knowledge in astronomy.

There are several achievements that can be singled out as new scientific results with great importance to the field. I will mention FRAM first. A detailed knowledge of the atmospheric conditions at the experiment's site is of crucial importance for the successful operation of the Auger fluorescence telescopes. Uncertainties in atmospheric parameters are a main source of systematic errors on the energy estimate for the Auger fluorescence detector. With FRAM, Michael Prouza has added a new type of monitoring instrument to the observatory. The main advantage of FRAM is of course that the observation of stars is non-invasive, *i.e.* it does not impact the observation of air showers by the fluorescence detectors at all. This is in contrast to the LIDAR system, which causes significant dead time in the fluorescence detectors. Michael Prouza has demonstrated that atmospheric monitoring using star light is feasible. FRAM is of great importance to Auger, but the technique of star observations will also be very valuable for other future observatories. It is not limited to cosmic ray physics, but can be used in other areas as well, for example in gamma ray astronomy.

The second important result is the development and application of a procedure to check and monitor the pointing accuracy of fluorescence detectors. This method is based on the signal that stars produce when crossing the field of view of a photomultiplier tube. Michael Prouza has developed sophisticated algorithms to detect these crossings, identify

the observed star and test the accuracy of the telescope's pointing. While the method is in general very elegant, it sounds easier than it actually is. Many systematics can produce "fake" star signals and complicate the procedure. Prouza has solved the many systematic problems of the method and applied it to the Auger air fluorescence detectors. Obviously, this is of great importance to Auger, and the method is general enough that it can used in future air fluorescence detectors.

I briefly mention two other important contributions to the field which are described in this thesis. Michael Prouza has studied the possibility of running the Auger fluorescence detectors during moon light. To my knowledge, this has not been done before by any previous experiment. Prouza was able to increase the duty cycle of the fluorescence detectors by about 20 %. Since the duty cycle is low to begin with, a substantial increase is of crucial importance. It will not only increase the amount of data of the highest quality, but also impact the systematic error on the energy estimate of the ground array, which is currently dominated by errors stemming from poor statistics.

Last, Michael Prouza has continued and extended a project he has worked on for his diploma thesis, a study of the influence of Galactic magnetic fields on particle propagation. This work has been published in peer-reviewed journals.

In addition to the descriptions of these achievements, the thesis also gives a very comprehensive overview of virtually all aspects of ultra–high-energy cosmic ray physics. It includes a survey of current and past instruments, a summary of the phenomenology as well as the observational status of high-energy cosmic ray physics, and an impressive list of references. The writing style conveys the enthusiasm that Prouza has brought to his work. Especially in the chapter on FRAM, the reader feels that this project is very near to his heart.

### Questions for the candidate

Here are several questions for the candidate which can be asked at the time of his defense.

(1) The caption to Figure 2.1 mentions a third feature in the cosmic ray flux, the "second knee." Has this feature been unambiguously detected ? What are possible explanations for this break in the energy spectrum ?

(2) The energy spectrum of cosmic rays is typically shown as "$flux \times E^3$ versus $E$" rather than simply "$flux$ versus $E$" (see for example Fig. 2.11). In that case, the interpretation of errors becomes rather tricky, since the errors on the x-axis and the y-axis are now correlated. Let us assume for example that all AGASA energies are overestimated by 25 %. In a simple "$flux$ versus $E$"-plot, we would shift the AGASA distribution by 25 % in the x-direction.

In a "$flux \times E^3$ versus $E$"-plot, this is more complicated. How would one move AGASA's curve in this case ?

(3) Section 6.3.2 briefly mentions another very interesting feature of FRAM, the possibility to detect optical counterparts of gamma ray bursts. How does FRAM's sensitivity compare to that of other experiments searching for optical counterparts, and what can we learn from such observations ?

**Summary statement**

With his thesis work, Michael Prouza has demonstrated his ability to pursue creative scientific research. The results of his work are of great importance to the Auger experiment and astroparticle physics in general. His thesis conveys a sense of the enthusiasm he brings to his work. I recommend that he obtain his degree after a successful defense. Please feel free to contact me if you need additional information.

Sincerely,

[redacted]

Assoc. Professor of Physics