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Marco Vignati

Model of the Response Function of CUORE Bolometers

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Model of the Response Function of CUORE Bolometers

Doctoral Thesis accepted by Dipartimento di Fisica, Sapienza Università di Roma, Rome, Italy

Springer

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A mio nonno

Supervisor's Foreword

In the quest of understanding the fundamental physics law of Nature, neutrinos play a special role. The observation of the neutrino mixing, calling for a finite neutrino mass, is the most solid experimental evidence that the Standard Model of Electroweak Interactions is incomplete and points to the existence of some form of New Physics. At the same time the only viable explanation of the matter–anti-matter asymmetry, the justification for our very existence, available today is based on the Leptogenesis, and this again points to the importance of neutrino properties understanding. The two most outstanding questions in neutrino physics are:

- Is the neutrino a Majorana particle?
- What is the absolute neutrino mass?

If neutrinos are Majorana particles then there is one (and the only one experimentally viable) process that can test this property. This process is the neutrinoless double beta decay that if observed would also set the scale for the absolute neutrino mass.

The experiment that has the greatest chance in the next years to test the neutrino nature is CUORE, performed at laboratori Nazionali del Gran Sasso (Italy).

This experiment is composed by about 1000 TeO_2 crystals operated as bolometers at a temperature of 10 mK. For many applications, phonon-mediated particle detectors operated at low temperatures (defined "bolometers") provide better energy resolution, lower energy threshold and broader material choice than the conventional detectors. The signal observed in the bolometric detectors, however, has complicated and unwanted features that could limit the success of the research. The energy resolution can be spoiled by temperature instabilities of the cryogenic setup, and the energy calibration is hard to parametrize. Moreover a faithful modeling of the bolometric signal is needed to evaluate the efficiencies of reconstructing the signal in the data analysis. Since years the response function of the detectors was not fully understood, slowing down the progress of the experiments in the field.

In this work Marco Vignati introduces a model that explains the unwanted features of the signal, and develops a method to correct them. There are no free parameters in the model, making it reliable and well understood. The application to test bolometers showed that the dependence of the response function on the detector temperature is removed, and that the calibration function can be reduced to a line. This has important implications for CUORE. The simplification of the calibration function and the correction of the response instabilities will reduce the time spent in calibrating the detector, which currently affects considerably the live time of the experiment. Starting from his model Marco Vignati developed a simulation of the signal that is able to reproduce all the needed features. This tool is now widely used by our colleagues to test and improve the data analysis.

It has to be remarked that the model can be applied to different kinds of large mass bolometric detectors, making it usable in other experiments.

Roma, March 2011 Fernando Ferroni

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Finally, thanks to my family for always following me and to Benedetta, for being ...

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Chapter 1
Neutrino Masses and Double Beta Decay

In 1914 Chadwick observed that the electrons emitted in β decays have a continuous spectrum, unlike what happens in α and γ decays. Nevertheless, if the decay products were only an electron and a nucleus, electrons would have necessarily a monochromatic spectrum. To overcome this paradox, Pauli proposed a "desperate way out" to save energy conservation, introducing a new particle that was not detected in the decay, the "neutron". After that the true neutron was identified by Chadwick, the new particle was renamed by Fermi "neutrino" (ν). Electron neutrinos were detected for the first time by Cowan and Reines in 1956 and found to be left-handed in 1957. The muon neutrino was discovered in 1962, while the tau neutrino was not discovered until 2000.

Great interest in neutrino physics was raised by the discovery of flavor non-conservation. The first hints for this phenomenon date back to the late 1960s, when a deficit in the solar neutrino flux was observed. It took about 30 years to completely understand that neutrinos change flavor along the path from the sun to the earth. This phenomenon, named "oscillation", was predicted by Pontecorvo in 1956 and shows that neutrinos have mass. Oscillations were then observed also in neutrinos produced in the atmosphere by cosmic rays and in neutrinos produced in nuclear reactors and accelerators.

In the last decade much progress has been made in neutrino physics. Oscillation experiments provided a clearer picture of this elusive particle and we are now entering the era of precision measurements. There are however questions that cannot be addressed by oscillation experiments. The absolute mass scale of the neutrino is one of these, and it is considered a key quantity in many theories beyond the Standard Model of particle physics. Being only sensitive to squared mass differences, oscillation experiments are not able to measure this parameter. Moreover, the mechanism responsible for the generation of neutrino masses is still unknown.

Neutrinos are electrically neutral leptons, and the only carried charge is that of weak interactions. In the Standard Model there is no symmetry requiring conservation of lepton number, even though a violation has never been observed.

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