Third year Ph.D. report

Student: Alice Campani

Supervisors*:* Sergio Di Domizio and Marco Pallavicini

List of published articles*:*

[1] D.Q. Adams *et al.* (CUORE collaboration), "*Improved Limit on Neutrinoless Double Beta Decay in ^{130}Te with CUORE*", Phys. Rev. Lett. 124, 122501 (2020);

[2] *A. Campani et al.* (CUORE collaboration), "*Lowering the energy threshold of the CUORE experiment: Benefits in the Surface Alpha Events Reconstruction - Comparison between Optimum Trigger and Derivative Trigger Performance in the Search for $0\nu\beta\beta$",* J. Low Temp. Phys. 200(5), 321-330 (2020);

[3] I. Nutini et al. (CUORE collaboration), "*The CUORE detector and results*", J. Low Temp. Phys. 199, 519-528 (2020).

List of works under internal revision/other works *:*

[4] D. Q. Adams *et al.* (CUORE collaboration), "*Measurement of the $2\nu\beta\beta$ Decay Half-life of ^{130}Te with CUORE*";

[5] D. Q. Adams *et al.* (CUORE collaboration), "*Search for double beta decay of ^{130}Te to the 0^+ excited states of ^{130}Xe with the CUORE experiment*";

[6] G.Benato, A. Campani, G. Fantini, "*$0\nu\beta\beta$ decay analysis - PRL 2019, CUORE Internal Note*", CUORE collaboration Internal Note;

[7] A. Campani, G. Fantini, "*Line-shape and energy scale systematics on background data*", CUORE collaboration Internal Note.

Conferences:

- XXIX INTERNATIONAL CONFERENCE ON NEUTRINO PHYSICS, held in Chicago, USA (virtual meeting), 22 June- 3July 2020 (poster with the title "*The Bayesian software for the $0\nu\beta\beta$ CUORE analysis")*

Exams:

- Gravitational waves (G. Gemme, A. Chincarini, F. Sorrentino), I prepared a seminar about "*Advanced quantum techniques for gravitational waves detectors*".

Description of my research activities:

My research activity as a Ph.D. student is focused on the search for rare events with the CUORE experiment. Neutrinoless double beta decay ($0\nu\beta\beta$) is a rare, second-order nuclear transition forbidden by the Standard Model of Particle Physics that explicitly violates the lepton number symmetry by two units. CUORE (*Cryogenic Underground Observatory for Rare Events*) is a bolometric experiment located at the Laboratori Nazionali del Gran Sasso, whose primary goal is the search for $0\nu\beta\beta$ decay of ^{130}Te. Among other nuclei, ^{130}Te has the highest natural isotopic abundance (~34%) and its Q-value is ~2527.5 keV. The CUORE detector consists of an array of 988 natural TeO_2 cubic crystals, operated at ~11 mK thanks to a powerful ^{3}He/^{4}He dilution refrigerator. The total active mass is ~742 kg (~206 kg of ^{130}Te). The energy resolution (FWHM) at the Q-value is (7.0 ± 0.4) keV [1], our background in the ROI is $(1.38 \pm 0.07) \cdot 10^{-2}$ counts/keV/kg/yr [1]. In the context of CUORE activities, my main contribution is related to data analysis at different levels. During the online data acquisition, we save continuous detector waveforms and separately trigger them with a software *derivative trigger*. In order to study the low energy region of the spectrum, an alternative low-threshold trigger algorithm was developed and used to retrigger all the acquired data. Briefly, the CUORE data analysis includes pulse amplitude evaluation, stabilisation against thermal drifts and the event energy reconstruction. Since we expect that in ~88% of cases $0\nu\beta\beta$ will release the whole energy in the same crystal, we apply an anti-coincidence cut to exclude particle events that released their energy in more than one crystal within a certain time window. I compared the performance of the two trigger algorithms, focusing on the effects on the multi-crystal events reconstruction and, consequently, on the reconstruction of the background [2]. We finally blind our data to define an unbiased fit strategy. I gave my contribution to the last data release with the development of a new software for the $0\nu\beta\beta$ fit based on Bayesian statistical approach [6]. Among the improvements with respect to the previous CUORE data release, we introduced a new way to treat the systematic effects induced by the energy dependence of the detector response [7]. We found no evidence of $0\nu\beta\beta$ and were able to set the most stringent limit to date on ^{130}Te $0\nu\beta\beta$ half-life$3.2 \cdot 10^{25}$ yr [1]. Since CUORE is made of natural tellurium, decay searches of isotopes other than ^{130}Te are also possible. I'm currently leading the search for neutrinoless double beta decay with two positrons emission ($0\nu\beta^+\beta^+$) of ^{120}Te, in particular the mode in which one beta decay is replaced by electron capture ($0\nu\beta^+$EC). The Q value is ~1714.8 keV. Even if ^{120}Te isotopic abundance is low (~0.09%), this process has an extremely clean signature thanks to the presence of a final state positron with the consequent emission of two back-to-back 511 keV gammas. Six scenarios are possible, assuming that the X-ray or the Auger electron are fully absorbed in the same crystal and considering that each gamma can be either absorbed in the same or a neighbouring crystal or completely escape the detector. I'm developing the fit with an extended version (suitable for multi-crystal events) of the software prepared for ^{130}Te.