Alice Campani - second year phd report (XXXIII cycle)

Supervisors: Sergio Di Domizio and Marco Pallavicini

List of papers:

- *Results from the CUORE experiment* (published on Universe 2019, 5(1), 2 January 2019)
- *Measurement of the $2\nu\beta\beta$ Decay Half-life of ^{130}Te with CUORE* (in preparation, to be submitted to PRL)
- *Lowering the energy threshold of the CUORE experiment* (Low Temperature Detectors conference proceeding, submitted)
- A paper about the new limit on $0\nu\beta\beta$ decay half-life of ^{130}Te with CUORE (in preparation)
- A paper on the external detector calibration system (in preparation)

Conferences:

- *18th International Workshop on Low temperature detectors*, held in Milan, 22-26 July 2019 (poster about trigger algorithm effects on multi-site events reconstruction)
- 8th International conference on New Frontiers in Physics, held in Kolymbari (Crete), 21-29 August 2019 (invited talk about the first CUORE results and the most recent limit on the $2\nu\beta\beta$ decay half-life of ^{30}Te)

Attended schools: INFN School of Statistics, held in Paestum, 2-7 June 2019

Summary of my research activities:

During this year I gave my contribution to the CUORE experiment research with the following activities:

- analysis shift during December 2018 (low level analysis of a dataset);
- optimization of the derivative trigger algorithm to set the trigger thresholds for the new datasets acquired during 2019;
- preliminary comparison of Monte Carlo simulations and first measurements with the new external detector calibration system;
- reprocessing and finalization of the first CUORE datasets to extract a new limit on $0\nu\beta\beta$ of ^{130}Te;
- development of a new software (bayesian statistical approach) to perform the fit and set a limit on ^{130}Te $0\nu\beta\beta$ half-life;
- preparation of a paper with the most stringent limit to date on ^{30}Te $0\nu\beta\beta$ decay.

Description of my research subject:

My research activity as a phd student is focused on the search for neutrinoless double beta decay ($0\nu\beta\beta$) of ^{130}Te with the CUORE experiment.

Neutrinoless double beta decay is a rare, second order nuclear transition that occurs if neutrinos are massive Majorana particles and explicitly violates lepton number symmetry of the standard model of particle physics. The experimental signature of $0\nu\beta\beta$ is a sharp peak at the Q value of the decay in the summed energy spectrum of the two electrons emitted.

CUORE (*Cryogenic Underground Observatory for Rare Events*) is an experiment located at the Laboratori Nazionali del Gran Sasso searching for $0\nu\beta\beta$ of ^{130}Te. Among other nuclei, ^{130}Te has the highest natural isotopic abundance and its Q value is ~ 2527.5 keV. CUORE consists of an array of 988 natural TeO_2 cubic crystals grouped in 19 towers, for a total active mass of ~742 kg (~206 kg of ^{130}Te). The detector is operated at ~11 mK thanks to a powerful ^{3}He/^{4}He dilution refrigerator.Each bolometer in CUORE is instrumented with a germanium thermistor to record thermal pulses due to particle energy deposition. The typical physical event consists of a 10 seconds long window signal: the baseline indicates the temperature before the interaction, whereas the amplitude is proportional to the energy released in the particle interaction.

In the context of CUORE activities, I was analysis shifter during December 2018 and, as a consequence, I took care of the full dataset low level processing.

During the online data acquisition, we save continuous detector waveforms and separately trigger them with a software derivative trigger. Briefly, this algorithm acts on the rising edge of a pulse: a trigger is fired when the derivative of the pulse stays above a certain threshold for a minimum number of consecutive samples. Through this year I helped optimizing the derivative trigger algorithm in order to set the bolometers energy thresholds for all the datasets acquired during 2019.

Briefly, the CUORE data analysis consists of different steps, the most important ones include pulse amplitude evaluation by means of the optimum filter algorithm, amplitude stabilization against thermal drifts and then the event energy reconstruction. Then, a series of cuts is applied to signals in order to reliably identify $0\nu\beta\beta$ candidate events. Among them, we exclude noisy periods and apply an anti-coincidence cut to exclude particle events that released their energy in more than one crystal within a certain time window. The reason is that we expect from Monte Carlo simulations that the largest fraction of $0\nu\beta\beta$ events (~ 88%) will release the whole energy in the same crystal.

In CUORE we perform particle events calibration with a set of radioactive sources that are periodically introduced within the detector structure. With the help of Monte Carlo simulations, we improved our calibration system by replacing ^{232}Th strings with a combination of ^{232}Th and ^{60}Co. Our aim is both to improve our energy resolution and to minimize the duration of calibration periods. We tested the new calibration system during December 2018 data taking so I was involved in the comparison of Monte Carlo simulations and first calibration data, mainly to validate the new calibration setup and to verify the agreement between simulated/measured rates and spectra. Our preliminary result showed that the new calibration setup gives reliable results and confirmed the reproducibility of calibration measurements.

In the context of data analysis, I also took part to the full data reprocessing and finalisation that has been performed during the last months. We selected the first seven datasets that were acquired from the the beginning of CUORE activity (2017) to the beginning of July 2019 to perform a high sensitivity search for ^{130}Te $0\nu\beta\beta$ decay. I was involved both in the optimization of the analysis tools to improve our detection efficiency and background rejection in the region of interest and in the selection of the final cuts to identify the spectrum for $0\nu\beta\beta$ search.

I gave my contribution to the development of a new software based on a bayesian statistical approach to perform the $0\nu\beta\beta$ analysis and fit. We introduced several improvements with respect to the one used for the first CUORE analysis, namely we added the possibility to perform the fit with different parameters configuration and included the systematic effects accounting in terms of nuisance parameters added to the model fit function. In particular, we include a bias on the position of the peak and the energy resolution scaling at the Q value to take into account both the energy dependence of the resolution and any difference existing between calibration and background.

Using the new analysis tools, we performed the fit and found no evidence of $0\nu\beta\beta$. Thus, we set a preliminary limit on the half-life of $0\nu\beta\beta$ ^{130}Te of 2.3 10^{25} yr (90 % C.L., statistical only). This is the most stringent limit up to date on neutrinoless double beta decay of ^{130}Te.

Assuming $0\nu\beta\beta$ is mediated by the light neutrino exchange (simplest model), we can interpret this result as a limit on the effective Majorana neutrino mass: $m_{\beta\beta} < 0.09$-0.42 eV (90 % C.L.). At the moment, I'm working on the preparation of a publication to present the new CUORE results.