PROCEEDINGS OF SCIENCE

CUPID-0: cryogenic calorimeters with light and heat read-out for $0\nu\beta\beta$ searches

N. Casali[∗a], **O. Azzolini**[b], **M. T. Barrera**[b], **J. W. Beeman**[c], **F. Bellini**[a,d], **M. Beretta**[e,f], **M. Biassoni**[f], **C. Brofferio**[e,f],**C. Bucci**[g], **L. Canonica**[g], **S. Capelli**[e,f], **L. Cardani**[a], **P. Carniti**[e,f], **L. Cassina**[e,f], **M. Clemenza**[e,f], **O. Cremonesi**[f], **A. Cruciani**[a], **A. D'Addabbo**[g,h], **I. Dafinei**[a], **S. Di Domizio**[i,l], **F. Ferroni**[a,d], **L. Gironi**[e,f], **A. Giuliani**[m,n], **P. Gorla**[g], **C. Gotti**[e,f], **G. Keppel**[b], **M. Martinez**[a,d], **S. Morganti**[a], **S. Nagorny**[g,h], **M. Nastasi**[e,f], **S. Nisi**[g], **C. Nones**[o], **D. Orlandi**[g], **L. Pagnanini**[e,f], **M. Pallavicini**[i,l], **V. Palmieri**[b], **L. Pattavina**[g,h], **M. Pavan**[e,f], **G. Pessina**[f], **V. Pettinacci**[a], **S. Pirro**[g], **S. Pozzi**[e,f], **E. Previtali**[f], **A. Puiu**[e,f], **C. Rusconi**[g,p], **K. Schäffner**[g,h], **C. Tomei**[a], **M. Vignati**[a] **and A. Zolotarova**[o]

[a] *INFN - Sezione di Roma, Roma I-00185 - Italy,*
[b] *INFN - Laboratori Nazionali di Legnaro, Legnaro (Padova) I-35020 - Italy,*
[c] *Materials Science Division, Lawrence Berkeley National Laboratory, Berkeley, CA 94720 - USA,*
[d] *Dipartimento di Fisica, Sapienza Università di Roma, Roma I-00185 - Italy,*
[e] *Dipartimento di Fisica, Università di Milano-Bicocca, Milano I-20126 - Italy,*
[f] *INFN - Sezione di Milano Bicocca, Milano I-20126 - Italy,*
[g] *INFN - Laboratori Nazionali del Gran Sasso, Assergi (L'Aquila) I-67010 - Italy,*
[h] *Gran Sasso Science Institute, 67100, L'Aquila - Italy,*
[i] *Dipartimento di Fisica, Università di Genova, Genova I-16146 - Italy,*
[l] *INFN - Sezione di Genova, Genova I-16146 - Italy,*
[m] *CSNSM, Univ. Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, 91405 Orsay, France,*
[n] *DiSAT, Università dell'Insubria, 22100 Como, Italy,*
[o] *IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France,*
[p] *Department of Physics and Astronomy, University of South Carolina, Columbia, SC 29208 - USA.*

E-mail: nicola.casali@roma1.infn.it.

Cryogenic calorimeters are currently used by experiments searching for neutrino-less double beta decay ($0\nu\beta\beta$). The sensitivity of these experiments is limited by the background coming from α radioactive contaminations. This background can be rejected exploiting the simultaneous read-out of light and heat in scintillating cryogenic calorimeters, because both the amplitude and the time development of the light signal depend on the nature of the particle interacting within. In this paper we present the CUPID-0 detector which represents the first demonstrator of this technique. Exploiting an array of 26 $Zn^{82}Se$ scintillating crystals operated as calorimeters and monitored by 31 cryogenic light detectors, CUPID-0 demonstrated the capability to completely reject the α background, paving the way for a next generation experiment searching for $0\nu\beta\beta$.

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∗Speaker.

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1. Introduction

Double Beta Decay ($\beta\beta$) is a nuclear process in which two neutrons simultaneously decay into protons with the emission of two electrons and two anti-neutrinos. Despite being the rarest nuclear process, it has already been observed for 11 nuclei with half-lives ranging from 10^{18} to 10^{24} yr [1]. In some extensions of the Standard Model of Particle Physics, this decay is expected to occur with no neutrino emission ($0\nu\beta\beta$) [2]. If observed, such transition would be the first evidence of lepton number violation, and an important hint of Physics beyond the Standard Model. Furthermore, the detection of $0\nu\beta\beta$ would allow to establish the nature of neutrinos, as it can occur only if neutrinos coincide with their own anti-particles, as predicted by Majorana [3].

Today, different collaborations are searching for $0\nu\beta\beta$ exploiting different technologies. In this contribution we present the CUPID-0 experiment, that is using cryogenic calorimeters to study the $0\nu\beta\beta$ of ^{82}Se.

2. CUPID-0

Cryogenic calorimeters can be sketched as crystals coupled to thermal sensors, and cooled at cryogenic temperature (about 10 mK). The energy deposit due to an interaction in the crystal produces a temperature increase, that is converted into an electrical signal by means of the thermal sensor (for CUPID-0, Neutron Transmutation Doped Ge thermistors [4]).

The most beautiful experiment based on this technology is CUORE [5, 6], that proved the possibility of operating a tonne-scale detector with excellent energy resolution (<1%) and efficiency (about 90%). The sensitivity of CUORE, today in data-taking in the underground Laboratori Nazionali del Gran Sasso (Italy), will be limited by the background induced by α particles emitted by close contaminations of the detector materials [7].

The CUPID-0 collaboration aims at rejecting such background via particle identification to pave the way for a next generation experiment: CUPID [8]. For this purpose, each calorimeter was coupled to a light detector, that enables particle ID by exploiting the different time development of light pulses produced by different particles [9, 10, 11].

The CUPID-0 collaboration decided to search for the $0\nu\beta\beta$ of ^{82}Se (Q-value: 2997.9±0.3 keV [12]). The natural Se was enriched to 96.3% in ^{82}Se. The enriched material was used to grow 24 crystals, subsequently doped with ZnSe(Al) to increase the light yield [13]. The final mass of CUPID-0 is 8.74 kg (3.41×10^{25} nuclei of ^{82}Se), plus other two natural crystals that were not used for the analysis of the $0\nu\beta\beta$ decay.

The light detectors used by CUPID-0 are high purity Ge disks operated as cryogenic calorimeters [14]. The 24 enriched and 2 natural ZnSe crystals were surrounded by a VIKUITI reflecting foil (3M), interleaved by light detectors and disposed in 5 towers using a high purity copper structure and PTFE pieces that serve as weak thermal link. The reader can find more details about the detector in Ref. [15].

The CUPID-0 detector was commissioned in May 2017. Ref. [16] presents the results obtained with the first physics run (3.44 kg·yr of ZnSe). Since then, we made another physics run (2.02 kg·yr) and we made a month-long calibration with ^{56}Co to study the calibration function and energy

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resolution in the region of interest. In this contribution we discuss the results corresponding to the full statistics.

3. Results and Perspectives

The first step of the CUPID-0 analysis consists in applying basic cuts to discard non-particle like events. We also apply a time-coincidence analysis by requesting that a single crystal triggers within a 20 ms time-window. Focussing on a 400 keV region centered around the Q-value of ^{82}Se (RoI), we obtain a background index of $(3.2\pm0.4)\times10^{-2}$ counts/keV/kg/yr (grey histogram of Fig. 1), with a signal efficiency of $(95\pm2)\%$.

We then exploit the light detectors to perform particle identification. For this purpose, we apply the matched filter algorithm to the light pulses and derive a shape parameter defined as $\frac{1}{A\omega_R}\sqrt{\sum_{i-i_M}^{i_M+\omega_R}(y_i - As_i)^2}$, where y_i is to the sample, i_M its maximum position, A its amplitude, s_i the ideal signal scaled to unitary amplitude (and aligned to y_i), ω_R the right width at half maximum of s_i, as described in Ref. [17]. This shape parameter is used to identify and reject α particles. After the application of this cut, the rate in the analysis window decreases to $(1.3\pm0.2)\times10^{-2}$ counts/keV/kg/yr (orange histogram of Fig. 1), with a signal efficiency of 100%.

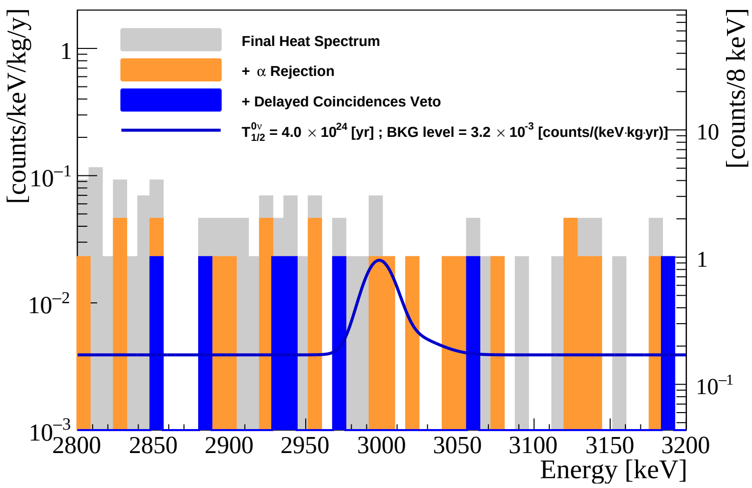

Figure 1: Grey, orange and glue histograms: energy spectra in the RoI obtained apply the cuts described in the text. The blu line represent the result of a simultaneous Unbinned Extended Maximum Likelihood fit over the blu spectrum, together with a hypothetical $0\nu\beta\beta$ signal corresponding to the 90% credible interval (C.I.) limit of $T^{0\nu}_{1/2} = 4.0\times10^{24}$ yr.

Finally, we apply a time-veto to reject possible ^{208}Tl decays due to crystals contaminations in ^{232}Th and its daughters. For this purpose, we take advantage from the short half-life of ^{208}Tl (about 3 minutes), and from the ease in tagging the decay of its mother, ^{212}Bi. When we observe a ^{212}Bi decay we open a time veto of 3 half-lives to reject ^{208}Tl interactions in the region of interest. To tag ^{212}Bi decays, we search both for α's with the nominal energy of ^{212}Bi, and for α's with energies down to 2 MeV, to account for a possible energy loss (for example if ^{212}Bi is located on the crystal surface). Applying the time-veto allows to decrease the rate in the analysis window to $3.2^{+1.3}_{-1.1}\times10^{-3}$ counts/keV/kg/yr (blue histogram of Fig. 1)).

The global signal efficiency, comprising the efficiency for the containment of the $0\nu\beta\beta$ electrons, the trigger and energy reconstruction efficiency, the data selection efficiency, and the dead-time induced by the time-veto, amounts to (75$\pm$2)%.

In summary, CUPID-0 is paving the way for a next generation project by proving that the background measured by CUORE ($\sim 10^{-2}$ counts/keV/kg/yr) can be reduced to $3.2^{1.3}_{1.1} \times 10^{-3}$ counts/keV/kg/yr via particle identification. Despite the small mass, CUPID-0 could set the most competitive lower limit on the half-life of ^{82}Se: $T^{0\nu}_{1/2} > 4.0 \times 10^{24}$ yr (90% C.I.), proving once more the potential of cryogenic calorimeters.

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