SEVENTH FRAMEWORK PROGRAM

“Ideas” Specific programme

European Research Council

Grant agreement for : Advanced Grant

Annex I- “ Description of Work”

Project acronym: LUCIFER

Project full title: **L**ow-background **U**nderground **C**ryogenic **I**nstallation **F**or **E**lusive **R**ates

Grant agreement: 247115

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Host Institution: Istituto Nazionale Fisica Nucleare - INFN

PART B: The Research Project

The Project proposal

i. State-of-the-art and objectives

Introduction

It is proposed to realize an experiment sensitive to a large fraction of the parameter space of the neutrino mass in the case it would be of the Majorana type. The experiment, named LUCIFER (**L**ow-background **U**nderground **C**ryogenic **I**nstallation **F**or **E**lusive **R**ates), aims to the observation of the neutrinoless double beta decay ($0\nu2\beta$), a phenomenon hypothesized very long ago but never observed. The experiment in case of success would demonstrate the Majorana nature of the neutrino mass and would at the same time allow to set the neutrino mass scale since it would measure a definite combination of the three mass eigenvalues. The limit that could be set, in case of non observation of the process would be the best ever set, having ruled out the entire, so-called, 'degenerate' mass region and having significantly penetrated the 'inverted hierarchy' one. At the same time the experiment would have demonstrated the winning technology for the exploration of the entire latter region. LUCIFER is based on the combination of know-how and technologies basically proven and at the same time call for a jump forward in terms of background reduction. We claim a value of less than 10^{-3} count/kg/year, a factor 100 better than anything seen so far in the field. The project presented in this document is therefore extremely ambitious. Its success relies on several aspects belonging to different fields of the research. Amongst them, two are keystones. The first will be the capability of producing the crystals of Zinc Selenide (the material chosen) with the required bolometric and scintillating quality, the second the design and realization of the calorimeter. In this respect the experiences of the Principal Investigator (Crystal Clear Collaboration, L3 BGO Calorimeter, CUORE crystals) and the Co-Investigator (MiBETA, Cuoricino, CUORE) do match nicely, strongly calling for their association in this project.

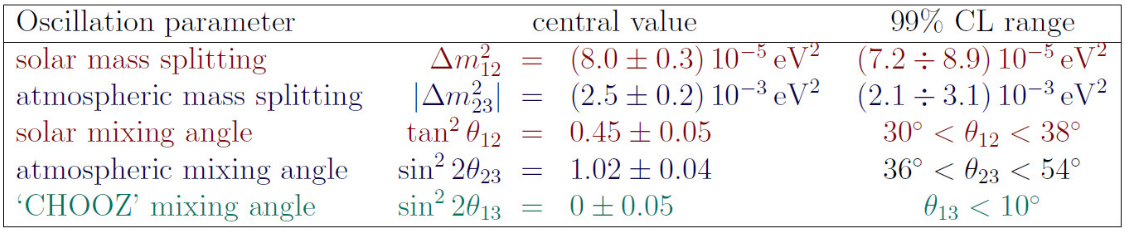
Neutrino Physics

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-antimatter asymmetry, the justification for our very existence, available today is based on the Leptogenesis and again points to the importance of neutrino properties understanding. The two most outstanding question in neutrino physics are:

- is the neutrino a Majorana particle

- what are the absolute neutrino masses

The oscillation experiments cannot answer any of the two questions. They, however, have set a stage that allows to know that neutrinos are massive, the mass difference squared between the neutrino species and two out of three of the mixing parameters, as shown in **Table B-I** [Vis08].



Oscillation parameter			central value	99% CL range
solar mass splitting	Δm^2_{12}	=	$(8.0 \pm 0.3)\,10^{-5}\,\mathrm{eV}^2$	$(7.2 \div 8.9)\,10^{-5}\,\mathrm{eV}^2$
atmospheric mass splitting	$\lvert\Delta m^2_{23}\rvert$	=	$(2.5 \pm 0.2)\,10^{-3}\,\mathrm{eV}^2$	$(2.1 \div 3.1)\,10^{-3}\,\mathrm{eV}^2$
solar mixing angle	$\tan^2\theta_{12}$	=	0.45 ± 0.05	$30° < \theta_{12} < 38°$
atmospheric mixing angle	$\sin^2 2\theta_{23}$	=	1.02 ± 0.04	$36° < \theta_{23} < 54°$
'CHOOZ' mixing angle	$\sin^2 2\theta_{13}$	=	0 ± 0.05	$\theta_{13} < 10°$

Table B-I - *Summary of present information on neutrino masses and mixings from oscillation data [Vis08].*

of their mass eigenstates (ν_1,ν_2,ν_3) as shown in **Fig. B-1**.

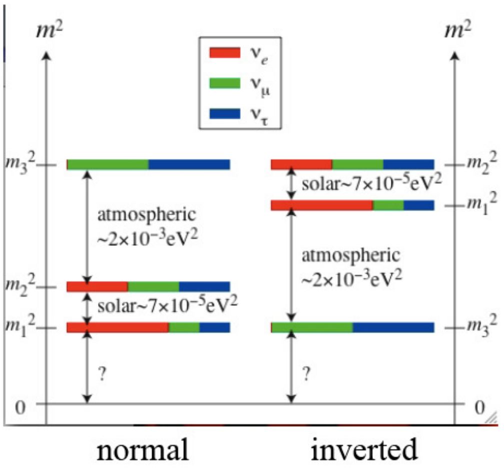


Fig. B-1 - *Possible neutrino spectra: normal (left) and inverted (right).*

One shall notice that the ambiguity inherent to the measurement of squared mass differences in the oscillation process leaves two possibilities for the hierarchical mass arrangements of neutrinos. There could also be a common baseline. The measured values of the neutrino mass differences are indeed tiny. Many orders of magnitude smaller than the mass of the lightest of charged leptons, the electron. Long ago E. Majorana formulated an elegant and minimal description [Maj37] of the neutrino field. The question is whether Nature makes use of this simplicity. Seventy years after, Majorana neutrinos are still an exciting possibility, indeed the best description we can find for the physical neutrinos. Majorana neutrino may explain the dominance of matter over antimatter in our Universe, from which asymmetry our very same existence depends. Until the discovery of the massive nature of neutrinos no much attention was paid to the issue of Majorana neutrino: if neutrinos are massless, as everybody believed, it did not matter. The Standard Theory changed the situation and it came (slowly) to be realized that the chiral symmetry is broken, so that there is no reason a priori to expect massless neutrinos and that a Dirac neutrino mass requires a right-handed (sterile, i.e. not interacting) neutrino, but then why neutrinos are so much lighter than the charged leptons or quark?

Majorana mass and weak isospin selection rules make it possible to find a natural explanation to the smallness of neutrino mass. The pattern of neutrino masses and mixing admit an elegant solution, the so-called see-saw mechanism [Min77]. Now we come to our project. If neutrinos are Majorana particle than there is one (and the only one experimentally viable) process that can test this property. The neutrinoless double beta decay.

Neutrinoless Double Beta Decay

Double beta decay (DBD) was suggested by M.Goeppert Mayer [MGM35] just one year after the Fermi theory of weak interactions. This process consists in the direct transition of the nucleus (A,Z) to its isobar (A,Z+2) when the direct decay of (A,Z) is energetically forbidden. The process $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\nu}_e$ is allowed by the lepton conservation law and has been found in different nuclei and in some case also in decays to excited nuclear levels. The Majorana nature of neutrinos would allow also the process: $(A,Z) \rightarrow (A,Z+2) + 2e^-$. In this case (neutrinoless double beta decay - 0ν2β) the two electrons share the total transition energy since the nuclear recoil energy is negligible. As a consequence a peak would appear corresponding to the total transition energy in the spectrum of the sum of the two electron energies (Q-value of the process). The rate of neutrinoless DBD

$$\Gamma_{0\nu 2\beta} = G \cdot \left|M^2\right| \cdot \left|m_{ee}\right|^2$$

is proportional to a phase term, which is reasonably easy to be calculated, to the square of the effective neutrino mass m_{ee} and to the square of the nuclear matrix elements. The effective neutrino mass can be parameterized as a function of the known neutrino parameters measured by the oscillation experiments through the expression:

$$m_{ee} = \sum_i V_{ei}^2 m_i = \cos^2\theta_{13}(m_1 e^{2i\beta}\cos^2\theta_{12} + m_2 e^{2i\alpha}\sin^2\theta_{12}) + m_3\sin^2\theta_{13}$$

that accounts for the mass differences, the mixing angles and the unknown Majorana phases.

Pictorially the scenario is reported in **Fig. B-2**.

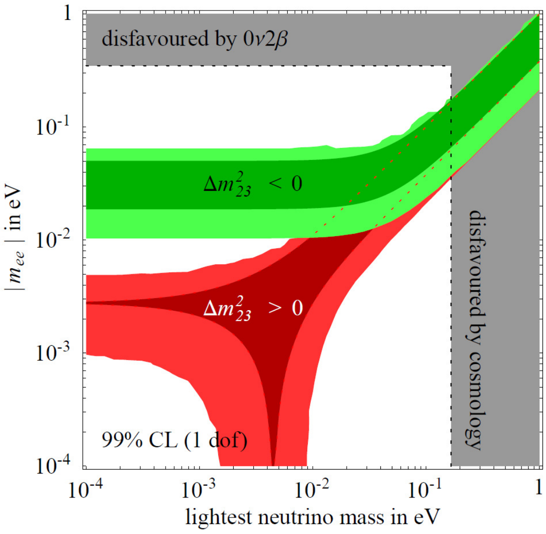


Fig. B-2 – *The effective neutrino mass m_{ee} reported as a function of the lightest neutrino mass. The three cases discussed in the text (degenerate, inverted, normal ordering) are clearly appreciable [Vis08].*

The darker regions show how the ranges would shrink if the present best-values of oscillation parameters were confirmed with negligible error. The three cases (degenerate, inverted, normal) are clearly separated.

M is the nuclear 0ν2β matrix element, plagued by a sizable theoretical uncertainty. The evaluation of this last has been and is carried out in the last decades by many authors leading to results which are often in considerable disagreement among themselves. Various approaches [ME08] have been taken: Shell Model, Quasiparticle Random Phase Approximation (QRPA, Renormalized QRPA), pnQRPA etc. Significative improvements have been seen recently: **Fig. B-3** summarizes the situation.

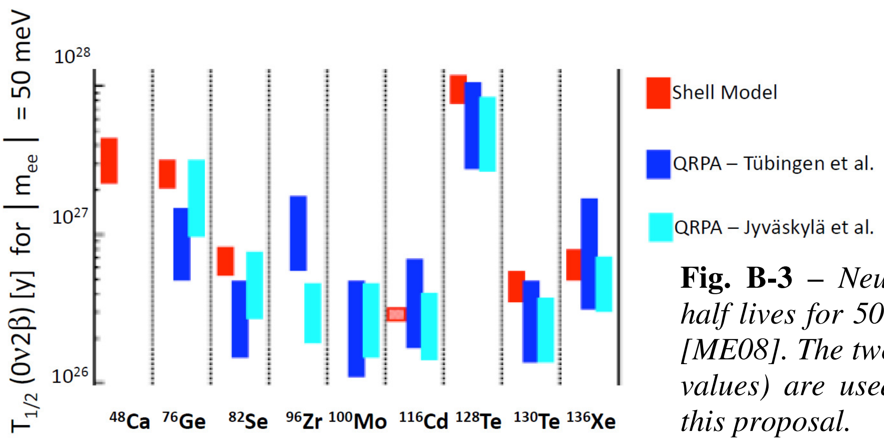


Fig. B-3 – *Neutrinoless double beta decay half lives for 50 meV effective neutrino mass [ME08]. The two QRPA calculations (central values) are used to evaluate sensitivities in this proposal.*

At the end of the day lifetimes are in the ballpark of 10^{26} years. A few decays per 100 kg of isotope per year!! In a realistic experiment we shall observe a signal proportional to time, rate, isotopic fraction, nuclei and efficiency:

$$N_{sig} = T \cdot \Gamma_{0\nu 2\beta} \cdot f \cdot N \cdot \varepsilon$$

while the background

$$N_{bkg} = T \cdot \Delta E \cdot ({}^{d\Gamma_b}\!/_{dE}) \cdot N$$

will depend on its energy shape and the energy resolution of the detector. The figure of merit of the experiment can be written as:

$$F = \frac{N_{sig}}{N_{bkg}} = \Gamma_{0\nu 2\beta} \cdot f \cdot \varepsilon \sqrt{\frac{N \cdot T}{\Delta E \cdot {}^{d\Gamma_b}\!/_{dE}}}$$

The most important remark is that the sensitivity to signal goes linearly with isotopic fraction and efficiency, as the square root of time and mass and worse , given the quadratic dependence of Γ on m_{ee}, the improvements on the estimate of neutrino mass is only to power 1/4. The route for the best possible experiment is therefore traced: isotopic enrichment, unity efficiency, extreme energy resolution, extremely low radioactivity, alpha to electron separation, all in order to have zero background or the closest approximation to it.

Bolometric Technique and Double Beta Decay

The history of DBD and that of the bolometric technique have been deeply entangled in the last two decades. Since when bolometers were proposed as innovative particle detectors, the search for DBD was predicted to be one of their most promising applications [FioNii84]. The reasons will result clear after a short review of this technology.

For many applications, phonon-mediated particle detectors (PMD) operated at low temperatures (often defined ‘bolometers’) [Giu92-01] provide better energy resolution, lower energy thresholds and broader material choice than conventional detectors. PMDs were proposed initially as perfect calorimeters, i.e. as devices able to thermalize fully the energy released by the impinging particle. In this approach, the energy deposited by a single quantum into an energy absorber (weakly connected to a heat sink) determines an increase of its temperature T. This temperature variation corresponds simply to the ratio between the energy released by the particle and the heat capacity C of the absorber. The only requirements are therefore to operate the device at low temperatures (usually < 0.1 K and sometimes < 0.015 K) in order to make the heat capacity of the device low enough, and to have a sensitive thermometer coupled to the energy absorber. The thermometer is usually a resistive element with a strong dependence of the resistance on the temperature. It can be either a semiconductor thermistor, as proposed here, or a superconducting film kept at the transition edge. In a more general approach, when the thermalization of the deposited energy is not guaranteed, the thermometer should be more correctly defined as a phonon-sensor, as the phonon energy distribution is not necessarily in equilibrium.

The energy absorbing part of the detector is made usually of a diamagnetic, dielectric material in order to avoid dangerous contributions to the specific heat in addition to the Debye term, proportional to $(T/\theta)^3$ at low temperatures. In such devices, the energy resolution can be fantastically good and close to the so (but not properly) called thermodynamic limit $\Delta E_{rms} \sim (kTC)^{1/2}$ [Math82-84]. For instance, this limit is of the order of 30 eV for a 1 kg TeO_2 crystal operated at 10 mK. Normally, spurious noise sources make real resolutions 1-2 orders of magnitude worse, but anyway close to or better than those achievable by state-of-the-art conventional detectors.

Semiconductor thermistors consist usually of Ge or Si small crystals with a net dopant concentration slightly below the metal-insulator transition. This implies a steep dependence of the sensor resistivity on the temperature at low temperatures, where the Variable Range Hopping conduction mechanism dominates. These high impedance sensors (tipically 1-100 MΩ) are usually parameterized by the sensitivity A, defined as $-d\,log R/d\,log T$, which typically ranges from 1 to 10 in the operation temperature range. A thermal decoupling between phonons and electrons appearing at low temperatures limits the sensor performance. This phenomenon, whose theoretical bases are not very clear, can be well represented by a finite thermal conductance $G_{e\text{-}ph}$ between phonons and electrons. Of course, this decoupling tends to spoil detector performances: it causes long signal risetimes and incomplete transmission of energy to the electrons of the thermistor. Since $G_{e\text{-}ph}$ is proportional to the thermistor volume, it is convenient to realize large thermistors, without exceeding of course the heat capacity of the energy absorber. A very useful technique to dope uniformly large volumes is the Neutron Transmutation Doping (NTD) [Hal85]. In this approach, which is commonly used for Ge, the semiconductor sample is bombarded by neutrons, which induce nuclear reactions on the various target isotopes leading to the formation of n- and p dopants. A thermal treatment is necessary to activate the dopants. Ge NTD thermistors with a mass of the order of 10 mg are proposed for the present project.

Let’s come now to the application to DBD. A very sensitive approach for the study of this process consists in developing a device which is source and detector of the phenomenon at the same time. In this method, the detector containing the candidate nuclides must be massive (of the order of 100-1000 kg for new generation experiments). Furthermore, it must exhibit high energy resolution and low radioactive background. Energy resolution is crucial since the signal is a peak in the energy spectrum of the detector positioned exactly at the Q-value of the reaction. This peak must be discriminated over the background and therefore has to be narrow. Bolometric detection of particles is clearly able to provide all the required features. High energy resolution is one of the characteristic of this technology. Ultra-pure crystals up to 100-1000 g can be grown for interesting materials, containing appealing candidates. Since the only characteristic required to the detector material is to have a low specific heat at low temperatures, many choices are possible. In a sentence, bolometers represent the generalization of the Ge diode technique (which is usable only for the rather-low-Q-value candidate ^{76}Ge) to the majority of the interesting candidates. Up to now, the choice has fallen on natural TeO_2 (tellurite) that has reasonable mechanical and thermal properties together with a very large (27% in mass) content of the DBD candidate ^{130}Te. That makes the request of enrichment not compulsory, as it is for other interesting isotopes. This feature explains the success of CUORICINO [Qino08] (presently the most sensitive DBD experiment together with the controversial Heidelberg-Moscow search) and the excellent prospects for CUORE [Cuo03] (an experiment under construction capable to approach the inverted hierarchy region). Both are based on large arrays of TeO_2 bolometers.

There are very good arguments which show how CUORE can be defined as an observatory for the bolometric search for DBD. Bolometry allows to direct the search towards the most promising nuclei and, in case of suspected evidence, to test it over several candidates, providing a unique cross-check with very high sensitivity. **Table B-II** shows the most promising candidates and the corresponding bolometric materials.

Candidate Nucleus	*I. A. [%]*	*Q-value [keV]*	*Materials successfully tested as bolometers* *Compounds in bald are good scintillators at low temperatures*
^{130}Te	33.8	2527	TeO_2
^{116}Cd	7.5	2802	**$CdWO_4$, $CdMoO_4$**
^{76}Ge	7.8	2039	Ge
^{136}Xe	8.9	2479	**-**
^{82}Se	9.2	2995	**ZnSe**
^{100}Mo	9.6	3034	**$PbMoO_4$, $CaMoO_4$, $SrMoO_4$, $CdMoO_4$, $SrMoO_4$, $ZnMoO_4$,** Li_2MoO_4,$MgMoO_4$
^{96}Zr	2.8	3350	ZrO_2
^{150}Nd	5.6	3367	**-**
^{48}Ca	0.187	4270	**CaF_2, $CaMoO_4$**

Table B-II – *Successfully tested bolometric materials for DBD search. I.A. stands for Isotopic Abundance.*

High Q-values are preferred in DBD experiments, because they lead to a large space phase for the process and to lower background. Environmental gammas represent the main source of background for most of the present DBD experiments and arise mainly from the natural contamination in ^{238}U and ^{232}Th. The highest relevant gamma line in natural radioactivity is the 2615 keV line of ^{208}Tl, with a total branching ratio (BR) of 36% in the ^{232}Th decay chain. Above this energy there are only extremely rare high energy gamma rays from ^{214}Bi; the total BR in the energy window from 2615 up to 3270 keV is only 0.15% in the ^{238}U decay chain. It is therefore clear that a detector based on a DBD emitter with a Q-value above the 2615 keV line of ^{208}Tl represents the optimal starting point for a future experiment, as shown in **Fig. B-4**.

The added value of scintillating bolometers

We will discuss now the additional value brought by scintillating bolometers to the search for DBD in high Q-value candidates. When the energy absorber in a bolometer is an efficient scintillator at low temperatures, a small but significant fraction of the deposited energy (up to a few %) is converted into scintillation photons, while the remaining dominant part is detected as usual in the form of heat. The simultaneous detection of the scintillation light is a very powerful tool to identify the nature of the interacting particle, since the energy partition between phonons and photons is different for different types of quanta. In particular, a nuclear recoil can be separated by an electron recoil (much lower light yield), and an alpha particle by an electron or gamma (different, not always lower, light yield). The ratio of the light yield for an alpha particle or nuclear recoil to that of an electron or gamma is defined Quenching Factor (QF).

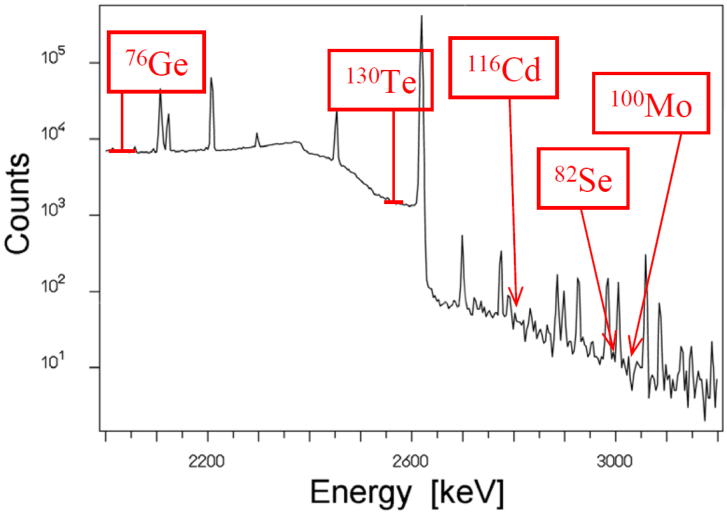


Fig. B-4 – *The positions of the Q-values of the most interesting DBD candidates are marked on a raw background γ spectrum collected in an underground laboratory. The advantage brought by Q > 2615 keV is strikingly evident.*

This method was proposed many years ago to identify the interactions of WIMPs in direct dark matter detectors [Ada95], and constitutes the basis for present (CRESST, ROSEBUD) and future (EURECA) dark matter experiments. The first simultaneous detection of phonon and photon was achieved more than a decade ago by the Milano group with a CaF_2 bolometer and a conventional Si photodiode as light detector, developed as a pilot device for the search for DBD in ^{48}Ca [Mil98].

In the following years, it became clear that the most obvious and effective method to detect scintillation photons in a very low temperature environment was to develop a dedicated bolometer, in the form of a thin slab, opaque to the emitted light and provided with its own phonon sensor. This auxiliary bolometer, normally a Si or Ge slab, is placed very close to a flat, optically polished, side of the main scintillating bolometer. The whole bolometric set-up is surrounded by a reflecting foil in order to maximise the light collection. More scintillating crystals can be read out by the same light detector. The very low threshold achievable with bolometers (tens of eV) makes them suitable devices for few-photon counting.

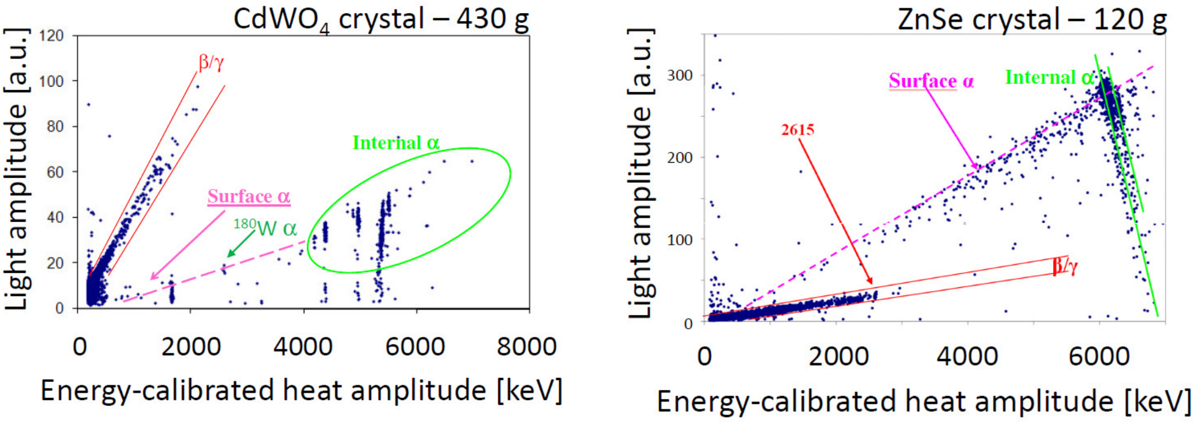


Fig. B-5 – *Scatter plots of light signal amplitudes vs. heat signal amplitudes (calibrated in energy) for a* $CdWO_4$ *(left) and a ZnSe crystal l(right). Alpha and gamma/beta events lie in different bands [Pir08].*

The ability to tag alpha particles is a formidable asset in the search for DBD in high Q-value candidates. In fact, the energy region above 2615 keV is dominated by alpha particles. The experience of Cuoricino shows clearly that energy-degraded alphas, emitted by the material surfaces facing the detectors or by the detector surfaces themselves, populate the spectral region between 2.5 and 4 MeV with a dangerous continuum, which would surely be the dominant background component for high-Q-value DBD candidates. Hence, the power of scintillating bolometers. Since the alpha QF is generally much lower than unity (with at least one significant exception, as discussed below), while the bolometric response is substantially independent of the nature of the interacting particle, it is clear that the simultaneous detection of scintillation light and heat signals, and the comparison of the respective amplitudes, produces a powerful tool for α/β discrimination.

As an example, **Fig. B-5** (left) reports the results achieved with a 430 g $CdWO_4$ bolometer operated in the Gran Sasso laboratory [Pir08], in the framework of of JRA2, UE financed, ILIAS Work Package. The figure shows, without need of additional comments, that the combination of a high Q-value candidate with a scintillating bolometer represents at the moment the best approximation to a zero-background experiment with high energy resolution and almost 100% efficiency, due to the coincidence of the source with the detector. In addition to $CdWO_4$, several scintillating crystals were preliminary tested with success. In particular, ZnSe showed a QF higher than 1, as shown in **Fig. B-5** (right). This compound will be extensively discussed in the following for its high potential, in spite of this odd behaviour.

During the R&D carried on with ZnSe scintillating bolometers aiming at alpha rejection, an additional interesting feature emerged, capable to increase further the α/β separation power. There was evidence that pulse shape discrimination can help in tagging alpha particles both in the heat and in the light channel. Appreciable differences in the full pulse evolution, at a first approximation reducible to a shorter decay time for the alpha signal in both channels, show up clearly. It is possible then to anticipate that the analysis of the events in a three-dimensional parameter space (decay time of the light signal, decay time of the heat signal, light-to-heat signal-amplitude ratio) should exhibit different well-separated populations, with alpha particles clearly distinct from β/γ events. This preliminary analysis suggests an alpha rejection efficiency better than 99% for ZnSe on a very conservative basis. The already demonstrated alpha background level, of the order of 0.05-0.1 counts/keV/kg/y and achieved by mere cleaning techniques, can then be reduced down to $\sim 10^{-3}$ counts/keV/kg/y and below.

ii. Methodology

The proposed experiment

We will describe an experiment based on a bolometer made by scintillating crystals. The experiment will be housed in an existing (at LNGS) cryostat previously used for the CUORICINO experiment and free by the time it will be requested by this experiment. We show that the amount of DBD emitter that can be housed in such a cryostat will be enough for the specifications of this project. In the following we will assume while designing the experiment this constrain.

Isotope choice

We limit the discussion to the nuclei that can be used to fabricate a scintillating crystal. We rely on this discussion on the already mentioned extensive R&D [Pir08] carried on several samples by dr. S. Pirro (INFN-Milano Bicocca unit) in the last few years at LNGS. Practical scintillators can be built out Mo, Cd and Se (see **Table B-II**). The candidates are $CdWO_4$, $ZnMoO_4$, ZnSe. In **Table B-III**, we compare here these nuclei with respect to physics sensitivity for a given mass, relative amount of DBD emitter in the crystal, enrichment cost, transition energy, background rejection factor. Although the discussion on the detector structure has yet to come we anticipate, for benchmarking goal, a total volume well compatible with the chosen cryostat, of $V = N_{cry} \times V_{cry} = 48 \times 125\ cm^3 = 6000\ cm^3$.

For ZnSe, in addition to the baseline conservative option of 48 crystals extensively discussed in section ‘Full detector structure’, we indicate two additional viable possibilities (examined later as well): (1) addition of 8 more crystals reducing the top lead shield in the cryostat; (2) crystal volume increased to 216 cm^3 keeping 44 crystals and giving up the internal lateral lead shield.

Transition energy does not indicate a preference. The three nuclei are equally good in terms of Q-value (2995 keV for ^{82}Se, 3034 keV for ^{100}Mo, 2809 keV for ^{116}Cd).

Crystal	*Isotope weight*	*Useful material*	*Half Life limit (10^{26}y)*	*Sensitivity* to m_{ee} (meV)*
$CdWO_4$	**^{116}Cd** 15.1 kg	32%	1.15	65-80
$ZnMoO_4$	**^{100}Mo** 11.3 kg	44%	1.27	67-73
ZnSe [baseline]	**^{82}Se** 17.6 kg	56%	2.31	52-65
ZnSe [option 1]	**^{82}Se** 20.5 kg	56%	2.59	49-61
ZnSe [option 2]	**^{82}Se** 27.8 kg	56%	3.20	44-55

** The 1σ sensitivity is calculated with the Feldman Cousins approach for 5 y running and a background index $d\Gamma_b/dE = 10^{-3}$ c/keV/Kg/y. The matrix elements come from the two most recent QRPA calculations [ME08]; the energy window is taken as 5 keV, compatible with the resolution achieved in TeO_2 macrobolometers and in scintillating-bolometer R&D. Enrichment is assumed to be 95%.*

Table B-III – *Sensitivity of three experimental options for a scintillating bolometer experiment on neutrinoless double beta decay compatible with the experimental volume of the CUORICINO cryostat.*

The next two elements to take into account are the quenching factor and the scintillation yield [Pir08], reported in **Table B-IV**.

Crystal	*LY (keV/MeV)*	*QF (α/β)*
$CdWO_4$	34	0.19
$ZnMoO_4$	1.4	0.16
ZnSe	7.4	4.2

Table B-IV – *Light yield (LY) and alpha quenching factors (QF) for interesting scintillating bolometers.*

And finally the cost and feasibility of enrichment. Both Mo and Se have been succesfully enriched in comparable (to our need) quantities. Recent quotes [Sar08] exists at a level of 50-80 Euro/g. Cd has additional difficulties and a plausible cost higher by more than a factor 2 (150-200 Euro/g). Selenium enrichment was done by an official tender (ILIAS JRA2/N4).

The final balance is in favour of ^{82}Se (ZnSe crystal) since sensitivity is the figure of merit of the experiment. The cost is affordable in the experiment budget (1.2 MEuro for the baseline option, taking the average of the price fork with 20% uncertainty at this point) and in spite of the opposite (to common sense) QF, it offers the requested rejection factor as already shown in **Fig. B-5** (right).

In ZnSe α particles have (much) higher light yield than β particles. Although not really welcome, this unexpected property, according to results of our preliminary investigations, to be confirmed by a careful study on the prototype crystals for the experiment, does not degrade the discrimination power of this material compared to the others and makes it compatible with the requirement of this high sensitivity experiment.

Enrichment, purification and crystal growth

As far as enrichment and purification of Selenium we rely on the long investigation that has already been performed within ILIAS JRA2/N4 by members of the NEMO collaboration for the enrichment of Se in ^{82}Se: about 4 kg of purified enriched selenium (at a level higher than 95%) were achieved thanks to enrichment plants located at Tomsk in Russia. Therefore, a significant part of the preliminary work to identify the producers and the purification procedures has already been performed and the cost evaluation of future experiments can be done on firm bases. Also the way for a chemical purification is paved following the developments described in [Arn01]. However, the measured concentration limits on ^{232}Th, ^{238}U and ^{226}Ra obtained in the last production batch of enriched Se already point to negligible background in the Double Beta Decay Region of Interest, without purification. This promising perspective is reinforced by the purification introduced by the crystallization process itself (a factor of about 100, observed for CUORE crystals, and rather independent from crystal type). The hard part of the work will be then in perfecting the crystal growth. There are several steps to be performed at the beginning of the research program to get to the point where one confidently can order to a vendor ZnSe crystals matching the experimental requirements.

A preliminary work will be dedicated to the study of the optical properties of the material and their low temperature dependence, taking into account the effect of impurities and local defects. The growth conditions and the post-growth treatment of the crystals will be also examined. A full characterization of the material is foreseen as well, in terms of a systematic measurement of electrical characteristics, photoluminescence, radioluminescence and thermo-stimulated luminescence. These introductive activities will help to define the precise nature of scintillation in undoped ZnSe crystals, including the origin of atypical value of the quenching factor. Other aspects that will be examined will be the thermal dependence of scintillation yield, the possible doping, and the technological limits for the purification of the raw material.

A second phase will be dedicated to test the limits of possible improvement of the scintillator performance, and the specifications to be asked to potential producers will be defined. The possibility of growing crystals of large dimensions (typically 500 g to 1 kg) and of high purity will be studied with selected crystal producers. At the moment, the company Alkor Technologies looks in the best position to be a commercial scientific partner in this enterprise, but other solutions will be considered.

At the end we will have a reproducible, reliable crystal growth technology developed in strict cooperation with the producer. For the certification of scintillation characteristics, dedicated procedures should be set up for the measurements of the optical transmission and the light yield of crystals at room and very low temperatures. Similar protocols will be dedicated to the radio-purity certification.

Single module structure

As every large mass bolometric detector, LUCIFER will consist of an array of tens of individual bolometers arranged in a close-packed configuration and housed by the same cryogenic infrastructure. This approach allows to achieve large masses (~ 50 kg) keeping the single-crystal mass reasonable (~ 0.5 kg) and providing a rough granularity, very helpful for background identification and rejection. The array will be composed by a set of identical elementary modules (EM), which will be described in this section.

The proposed structure of each EM exploits years' experience gathered during the development of past and present DBD TeO_2 experiments. The configuration here devised resembles closely the one selected and extensively tested for CUORE (and its demonstrator CUORE-0), with an additional light detector, designed according to the receipts developed during the scintillating-bolometer R&D. This choice minimizes the amount of work necessary to set up the detector structure, and allows to take advantage of a number of existing elements, such as the technical drawings for the holders, the realization procedures of the mechanical pieces, the optimised assembly environment and sequences, the read-out scheme including the cryostat wiring, and the related quality-control protocols.

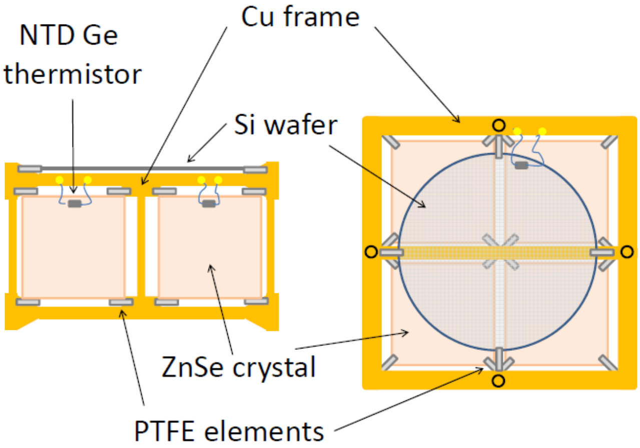


Fig. B-6 – *Elementary module of LUCIFER, with four ZnSe scintillating crystals read out by a single light detector. The ZnSe crystal is a cube (5 cm side), and the light detector a Si disk (9.5 cm diameter). L.eft: side view; Right: top view*

The EM structure is shown in **Fig. B-6**. Four ZnSe cubic crystals will be arranged in each EM. As in CUORE, the cubes will have 5 cm side, leading to a single crystal mass of 660 g (ZnSe density is 5.27 g/cm^3).

Two copper frames, connected by four copper columns, bound the EM above and below. These frames, which act as a 10 mK heat sink for the bolometers, hold 14 polytetrafluoroethylene (PTFE) elements serving as mechanical support and thermal link for the crystals. One NTD Ge thermistor is glued on each crystal, and two Au wires are ball-bonded from the thermistor contacts to pads located on the frames for the signal read-out. A resistive heater, to be used for the stabilization of the thermal response, is glued on the crystal as well, and read out as the thermistors. The module can be inscribed in a cylinder with 18 cm diameter, compatible with the CUORICINO cryostat in the present configuration. Its total height is 7 cm. A reflecting foil will be placed laterally connecting the two frames to improve the light collection.

The EM upper frame is designed so as to house an intrinsic-Si disk-shaped slab 0.5 mm thick and 9.5 cm diameter, acting as a photon absorber for the light detector. The option to use a square slab with 9.5 cm side (providing larger light collection) will be considered as well. The Si slab is placed above the ZnSe crystals and the PTFE elements supporting them, and will be kept by four PTFE clamps fixed at the frame. Again, an NTD Ge thermistor and a heater will be glued on the Si slab. This configuration allows the light detector to see the four crystals underneath, and to offer its upper face to the adjacent EM with its four ZnSe crystals.

We leave open the option to split the Si slab into four, each one matching the crystal face. This would increase the light collection efficiency and the sensitivity of the single light detector at a cost of increasing the number of read-out channels and a slightly more complex mechanical design. We consider also to replace Si with Ge as bolometric material for light detectors.

The definition of the final light detector configuration will depend upon the results of an optimization.

In terms of bolometric performance, on the basis of the results achieved so far with macro-bolometers an energy resolution of ~5 keV FWHM or even lower can be safely anticipated.

Full detector structure

The EMs described above will be stacked so as to form a tower (see **Fig. B-7**). The sequence will start from below with an isolated frame similar to the upper frame of the EM and containing a light detector. Then, 12 EMs will be assembled one above the other. The total tower height will be 85 cm, exploiting fully the available space in the CUORICINO cryostat in the present internal shielding arrangement. The total bolometric mass will be 31.7 kg, and the corresponding mass of the enriched material 17.6 kg.

The configuration here described is very conservative, and based on the preservation as complete as possible of already tested structures. However, other possibilities can be taken into consideration, with the aim to increase the total detector mass without moving to another cryostat. For instance, the two options considered in **Table B-III** and related discussion:

1. The internal lead shielding placed between the mixing chamber and the detector can be reduced or removed, allowing to house two more EMs. This would increase the total mass to 36.9 kg and the enriched one to 20.5 kg.
2. By removing the lateral lead shield, it would be possible to increase to 6 cm the side of the crystal cube, leading to a single crystal mass of about 1.1 kg (we remind that 1.2 kg TeO_2 crystals were successfully realized, with excellent energy resolution). The detector would be inscribed in a 20 cm diameter cylinder. In this case, rescaling opportunely all the elements described in the previous section, it would be possible to realize 11 EMs, for a total mass of 50 kg and enriched mass of 27.8 kg. This option depends of course on the success of the crystallization R&D and on the bolometric performance or very large mass ZnSe detectors, but looks quite reasonable.

The removal or the reduction of the internal shields may look dangerous. However, we remind that the gamma activity is not so harmful for scintillating bolometers, and that the CUORICINO cryostat is realized with low radioactivity materials. A Monte Carlo validation of the new proposed structures will be necessary anyhow.

The tower of ZnSe scintillating bolometers will be surrounded by a copper thermal shield and suspended using the same method successfully developed for CUORICINO, consisting of a stainless steel spring connected to the 50 mK plate of the fridge. The thermal link to the coldest fridge point, the so-called mixing chamber, will be assured by soft copper strips. The copper frames, the columns, the thermal shield will act as a isothermal 10 mK heat bath for all the detectors. The thermal impedance offered by the soft copper strips will allow to stabilize the tower temperature slightly above that of the mixing chamber through a heater.

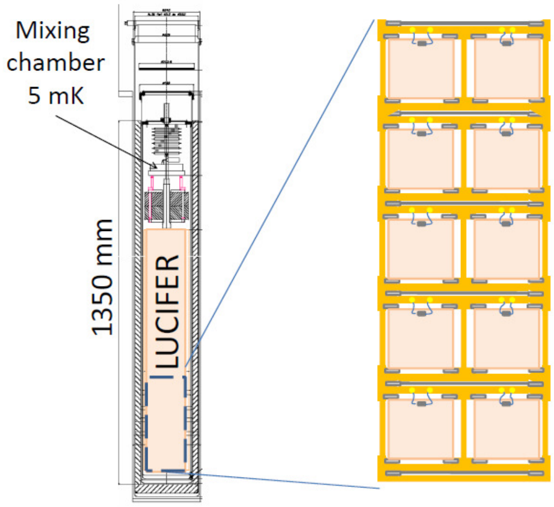


Fig. B-7 – *The LUCIFER tower inside the former CUORICINO cryostat. A detail of the tower, comprising 5 elementary modules, is shown on the right.*

The front end electronics, the post-amplifiers and the DAQ system will be exactly those used for CUORICINO. The calibration of the detectors will be performed with external gamma sources, as in CUORICINO.

Analysis and event classes

The analysis tools developed for CUORE can be used for LUCIFER, since they allow to extract the best estimate of the pulse amplitude through the optimum filter, to study the signal shapes through various shape parameters, and to accept or reject events on the basis of (anti)coincidence patterns among the various bolometric channels. Calibration and linearization of the energy spectra can be performed as in CUORICINO.

The particular configuration of the proposed scintillating bolometers define a very well characterized event class to which the double-beta-decay signal belongs, unlike alpha events and multiple-scattering gamma or neutron events. The CUORE analysis tools are already tailored to identify this event class, although they will be improved to meet the features of scintillating bolometers. Each ZnSe crystals is sandwiched between two light detectors, which will both collect light when energy is deposited in the main bolometer. Therefore, the event class corresponding to a potential signal will be characterized by:

1. A triple-coincidence signal in a ZnSe crystal and in the two light detectors which surround it;
2. Simultaneous signal in none of the remaining channels;

3. A light-to-heat signal amplitude ratio compatible with beta-like or gamma-like events;
4. A pulse shape in the light and heat channels compatible with beta-like or gamma-like events.

As far as the last two points are concerned, we will stress that no alpha source will be placed inside the refrigerator to evidence the alpha-event features. In fact, the analysis of the residual detector background will allow to extract them, due to unavoidable alpha contamination. In other terms, the detector will undergo a self calibration after few-month running.

Time schedule

The LUCIFER time schedule is reported below in the form of a Gantt diagram.

ACTIVITY AREA	TASKS	MONTHS									
		6	12	18	24	30	36	42	48	54	60
1. CRYSTAL GROWTH OPTIMIZATION	1.1 – STUDY OF SCINTILLATION PROPERTIES OF ZnSe	▨	▨								
	1.2 –CRYSTAL SPECIFICATIONS AND CONTACT WITH PRODUCERS	▨	▨	▨							
	1.3 – IMPLEMENTATION OF THE INDUSTRIAL PRODUCTION			▨	▨						
2. PRODUCTION OF THE ENRICHED CRYSTALS	2.1 –NEGOTIATION FOR THE ENRICHMENT- PREPRODUCTION	▨ ,	▨								
	2.2 – PRODUCTION OF THE ENRICHED MATERIAL		▨	▨	▨						
	2.3 – QUALITY CONTROL AND PURIFICATION OF ^{82}Se	▨	▨	▨	▨						
	2.4 – GROWTH OF THE ZnSe CRYSTALS WITH ENRICHED MATERIALS			▨	▨	▨					
3. OPTIMIZATION OF LIGHT DETECTORS	3.1 – CHOICE OF MATERIALS FOR LIGHT ABSORBERS	▨	▨								
	3.2 – REALIZATION AND TEST OF LIGHT DETECTOR PROTOTYPES		▨	▨							
	3.3 – FULL PRODUCTION OF THE LIGHT DETECTORS				▨	▨					
4. OPTIMIZATION OF ZnSe SCINTILLATING BOLOMETERS	4.1 – MATERIAL PROCUREMENT FOR BOLOMETER PROTOTYPES	▨									
	4.2 – ASSEMBLY AND OPERATION OF THE PROTOTYPES		▨	▨							
	4.3 – OPTIMIZATION OF LARGE MASS ZnSe BOLOMETERS			▨	▨						
5. LUCIFER ASSEMBLY	5.1 – THERMISTOR PROCUREMENT AND CHARACTERIZATION	▨	▨	▨							
	5.2 – SET-UP OF A RADIO-CLEAN, RADON-FREE ASSEMBLY ROOM				▨	▨					
	5.3 – REALIZATION OF THE MECHANICAL PIECES AND CLEANING			▨	▨	▨					
	5.4 – TOWER ASSEMBLY AND INSTALLATION IN CRYOSTAT						▨				
6. LUCIFER KICK-OFF	6.1 – ELECTRONICS AND DATA ANALYSIS SET-UP						▨				
	6.2 – TOWER COOL DOWN AND DETECTOR OPTIMIZATION							▨			
	6.3 – DATA TAKING								▨	▨	▨
	6.4 – FIRST PHYSICS RESULTS									▨	▨

We can define a few intermediate goals that can serve as milestones of the projects and will allow both us and the reviewers to monitor the progresses.

Goal 1: Completion of material enrichment , including QA/QC and purification (24 months)

The way to Goal 1 consists of the following steps:

1) 100 gr of enriched ^{82}Se in order to set up QC/QA procedure and to assess purity (0-6 months)
2) 1 Kg of enriched ^{82}Se to optimize crystal growing (6-12 months)
3) Full isotope production (12-24 months)

Goal 2: Completion of production of crystals (30 months)

The way to Goal 2 consists of the following steps:

1) Optimize scintillation yield of ZnSe crystals (0-12 months)
2) Set up QC/QA for production (0-12 months)
3) Production of a crystal starting with enriched material (12-18 months)
4) Test of a final elementary bolometer module (18-24)
5) Full crystal production (24-30 months)

Goal 3 : Production of light detectors (30 months)

The way to Goal 3 consists of the following steps:

1) Material choice (Si vs Ge) (0-12 months)
2) Shape optimization (12-18 months)
3) Full production of light sensors (18-30 months)

Goal 4 : Assembled detector (36 months)

The way to Goal 4 consists of the following steps:

1) Thermistors procurement (0-18 months)
2) Set up of a radon free assembly room (24-30 months)
3) Production of mechanical parts and cleaning (18-30 months)
4) Full detector assembly (30-36 months)

Goal 5 : Data taking (42 months)

The way to Goal 5 consists of the following steps:

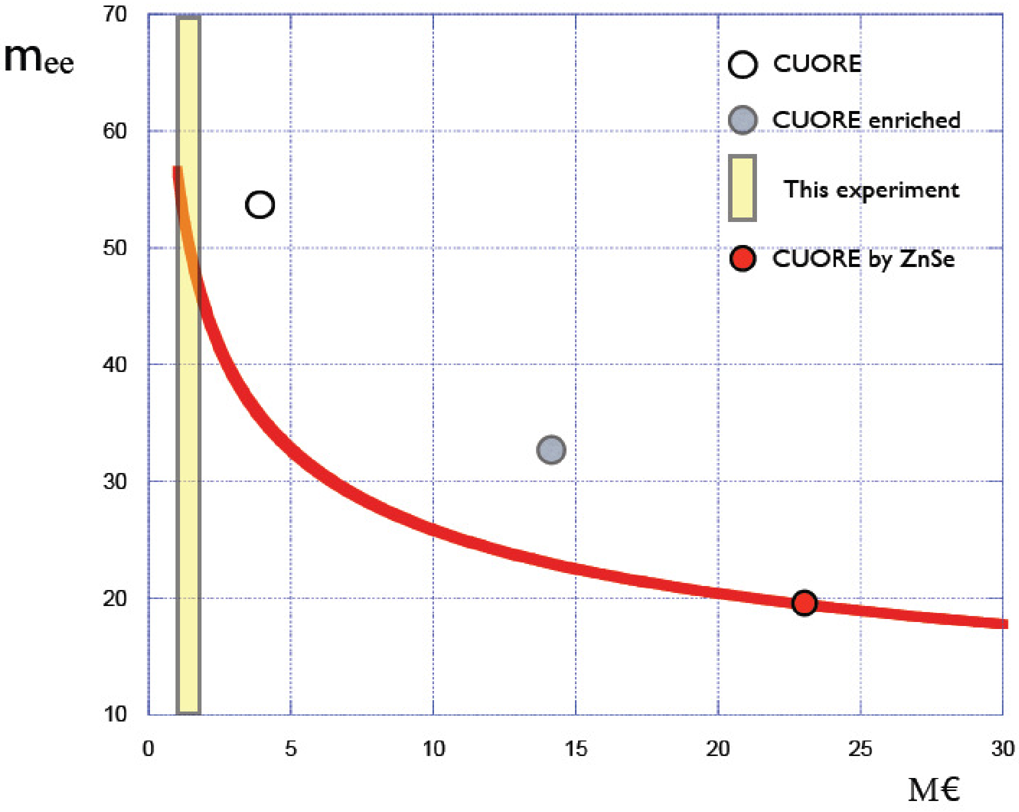
1) Electronics set up (36-42)
2) DAQ set up (36-42)
3) Detector cool-down and commissioning (36-42)
4) Start data taking (42->)

Goal 6 : Completion of project and Physics results (60)

International Context and Competition

There are several ongoing projects for n2b searches all over the world. However, only few have got a chance to go into construction phase. At this stage GERDA at LNGS is supposed to take data as early as this year with the declared scope of checking the Klapdor , severely controversial, claim and to test the technology for a successive phase 2. The somewhat unfavorable matrix element confines them above the 100 meV threshold. EXO is also about to start its adventure by making use of a LXe TPC. The goal is to prepare a much more ambitious, although quite far in time, experiment with higher mass and and the identification of the individual decayed nucleus . No date can be foreseen for it. SuperNEMO will be a natural continuation of the superb technology developed at NEMO3. An extensive R&D is going on: energy resolution and experiment size are the biggest problem. Again no clear date for the beginning of construction is in view. Finally, there is CUORE at LNGS, the natural expansion of the successful experiment Cuoricino.

We owe much of the experimental methodology of our proposal to the experience made in Cuoricino, CUORE and the related R&Ds. As we show in the figure below, that we consider a striking illustration of the potentiality of our proposal, the combination of the bolometric technique with the detection of the scintillation light makes a much more effective experiment. We plot the reach in terms of neutrino mass discovery potential versus the cost of the crystals (raw material, possible enrichment, purification and growth). The rest (dilution refrigerator, cryostat, mechanics, electronics, services, etc…) will be common. The red line is the physics reach of ZnSe with 10^{-3} c/keV/kg/y of background. The yellow band covers the uncertainty in the cost of the ^{82}Se enrichment for the proposed experiment.



The following table summarizes the scientific profile of the experiment, on the basis of the detector structure options mentioned above and with 10^{-3} c/keV/kg/y of background, 5 y live time and 5 keV energy window (compatible with the already achieved energy resolution in macrobolometers). Enrichment level is 97%. The two most recent QRPA nuclear matrix element calculations were considered. Sensitivities are evaluated with the Feldman Cousins method.

Crystal	*Isotope weight*	*Half Life limit [10^{26}y] (68% CL)*	*Range of cost (50-80 €/g) [M€]*	*Sensitivity to m_{ee} [meV] (68% CL)*	*Sensitivity to m_{ee} [meV] (90% CL)*
ZnSe [baseline]	**^{82}Se** 17.6 kg	2.31	0.88-1.41	52-65	70-87
ZnSe [option 1]	**^{82}Se** 20.5 kg	2.59	1.03-1.64	49-61	66-82
ZnSe [option 2]	**^{82}Se** 27.8 kg	3.20	1.39-2.24	44-55	59-73

Besides aiming to set the best upper limit ever, it is instructive to quote the discovery potential of the experiment, assuming 0 background, shown to be achievable by our preliminary studies. The lowest neutrino mass for an observed number of events which gives a statistical significance in excess of 3s would lie in the range 55-68 meV.

For the same cost the ZnSe always wins over CUORE with TeO_2, although both are getting close or even inside the inverted hierarchy mass region. The necessity of multiple experimental evidences to call victory in case of discovery strongly suggests to pursue the ^{82}Se way. Observing 0n2b with different nuclei is compulsory for two reasons: to be fully sure that the signal is not faked by a spurious line, and in view of theoretical uncertainties on the matrix elements. Besides, it is also the most promising avenue for any expansion towards higher sensitivities being the most cost effective and totally scalable.

Scientific impact and prospects

The proposed project aims to unveil the nature of the neutrino mass. It is the only project that could (will) be performed in the next couple of years with the potentiality of exploring (at least) a significant portion of the so-called inverted hierarchy region, beside the entire degenerate one. It is also a project with a degree of complementarity to others that will run at the same time and will make use of different isotopes (Tellurium for CUORE, Germanium for GERDA). This element is important once the problems in evaluating the expected lifetimes (nuclear matrix elements) are properly acknowledged.

A positive result of the experiment would give an answer to one of the fundamental questions open in Nature, that neutrino is a Majorana particle. Beside this fundamental assessment, it would constitute a proof of existence of New Physics at a scale much larger than the one of the electroweak interactions , so well described by the Standard Model. It would also confirm the brilliant, but so far completely untested, hypothesis of the 'see-saw' mechanism. Last and definitely not least it would give a scale to the absolute neutrino mass. Indeed an amazing set of fundamental results.

Of course one shall consider the possibility of ending with an upper limit on the lifetime (neutrino mass) rather than a value. Although this result might look disappointing, we strongly believe that this project, by setting the best limit ever and considered the very limited mass employed in the search (35 Kg !) will have the merit of indicating the way to go for yet another generation of experiments. The technology demonstrated by this project is indeed fully scalable, the cost will be set only by the enrichment. To get to the low boundary of the inverted hierarchy region (20 meV) a mass of 1 ton will be needed, the experiment will cost less than 40M€. A value that fits even too well into the forecast for future regional experiments on DBD.

The time for carrying on this project is now. Most of the basic R&D's have been performed all over the world, a significant fraction of them (high purity crystal growth and state of the art bolometric detectors) by the proponents of this experiment. For a modest cost and a reasonable amount of risk we strongly believe that the project should be executed.

iii. Resources

Here we describe the elements that bring to the cost estimate of the project. The proper breakdown will be given in the table of the section Resources.

a) Team costs

The time profile of personnel is shown in **Table B-V**. The PI and the Co-Investigator are both University Professors. They will remain in charge to their institutions. The presence at LNGS will be insured by taking on-leave of absence (up to two years) and by travelling (included in the travel expenses)***. Three key people, Ioan Dafinei (senior engineer, expertise in enrichment, purification and above all crystal growth), Stefano Pirro (senior researcher, expertise in neutrino physics and rare event searches, main author of the R&D on ZnSe) and Ezio Previtali (senior researcher, expertise in neutrino physics and ultra-low backgrounds technologies) found in-house (INFN staff).*** They will contribute a few months per year of their research time. We plan to hire temporary staff for a total of 13 persons-year mainly through art. 23 INFN. Their expertise shall be in cryogenics, operation of bolometers, analogic electronics and DAQ, low radioactivity. Cost of personnel, estimated on the basis of 49k€/y amounts to 637k€. Travel expenses are evaluated at 0.3M€.

Manpower/Year	**1**	**2**	**3**	**4**	**5**
PIs	10	10	24	18	10
INFN Staff	8	10	10	6	5
ERC personnel	24	36	36	36	24

Table B-V – *Time profile of the LUCIFER personnel in man-months*

b) Infrastructure and equipment

The experiment will be located at LNGS. We rely on an existing cryostat, belonging to INFN and used by CUORICINO. Mounting of the detector will be performed in existing clean rooms (Borexino or CUORE). Other requirements are minimal.

c) Detector

Most of the costs of the project are to be found here.

- Selenium metal, enrichment of ^{82}Se, possible purification: at very conservative estimate (based on ILIAS findings) of 65 €/g (all included) this will amount to 1.2 M€.
- Crystal growth (including R&D): 0.30 M€ for 48 crystals including 0.1 M€ of R&D and start-up (based on our past experience with other types of crystals)
- Light detectors, thermistors: 0.1 M€ (CUORE experience)
- Cu and mechanical structure: 0.1 M€ (CUORE experience)
- Cryogenics liquids and miscellanea: 0.1 M€ (CUORICINO experience)

d) Audit: 10 k€ are allocated for audit certification (3rd and 5th year) , which will be subcontracted.

The time distribution of resources, as presented in the B2 form and compatible with the above cost description, is presented below, in **Table B-VI**.

Table B-VI – *Time profile of the LUCIFER global costs*

	Cost Category	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total (Y1-5)**
Direct Costs:	*Personnel:*						
	PI	0	0	0	0	0	0
	Senior Staff	0	0	0	0	0	0
	Post docs	98000	147000	147000	147000	98000	637000
	Students	0	0	0	0	0	0
	Other	0	0	0	0	0	0
	Total Personnel:	98000	147000	147000	147000	98000	637000
	Other Direct Costs:						
	Equipment	0	0	0	0	0	0
	Consumables	630000	900000	230000	20000	20000	1800000
	Travel	20000	80000	90000	70000	40000	300000
	Publications, etc	0	0	0	0	0	0
	Other	0	0	0	0	0	0
	Total Other Direct Costs:	650000	980000	320000	90000	60000	2100000
	Total Direct Costs:	748000	1127000	467000	237000	158000	2737000
Indirect Costs (overheads):	Max 20% of Direct Costs	149600	225400	93400	47400	31600	547400
Subcontracting Costs:	(No overheads)	0	0	5000	0	5000	10000
Total Costs of project:	(by year and total)	897600	1352400	565400	284400	194600	**3294400**
Requested Grant:	(by year and total)	897600	1352400	565400	284400	194600	**3294400**

In the following section, a revised time distribution of the project cost is presented, which includes small modifications with respect to the B2 estimate.

iii. Ressources - Table 1

Costs Category	month 1 to 18	month 19 to 36	month 37 to 54	month 55 to 60	TOTAL
Personnel	73.500,00	245.000,00	245.000,00	73.500,00	637.000,00
Subcontracting		5.000,00		5.000,00	10.000,00
Equipment					0,00
Consumables	1.100.000,00	660.000,00	20.000,00	20.000,00	1.800.000,00
Travel	60.000,00	130.000,00	80.000,00	30.000,00	300.000,00
Publications					0,00
Sub-total Other Directs Costs	1.160.000,00	790.000,00	100.000,00	50.000,00	2.100.000,00
Overheads	246.700,00	207.000,00	69.000,00	24.700,00	547.400,00
TOTAL	**1.480.200,00**	**1.247.000,00**	**414.000,00**	**153.200,00**	**3.294.400,00**

Amount of Receipts

iii. Ressources - Table 2

„key intermediate goal", as defined in section 2.ii.	Estimated % of total requested grant	Expected to be completed on month :	Comment
Goal 1	45%	24	Completion of material enrichment including QC/QA and purification
Goal 2	22%	24	Completion of production of crystals
Goal 3	12%	30	Production of light detectors
Goal 4	11%	42	Assembled detectors
Goal 5	4%	48	Start of data taking
Goal 6	6%	60	Completion of project and Physics Results
Total	100%		

PART C: The Research Environment

The host institution will be Istituto Nazionale di Fisica Nucleare (INFN). The INFN is the Italian reaserch institution devoted to the study of the fundamental constituents of matter, and conducts theoretical and experimental research in the fields of subnuclear, nuclear, and astroparticle physics. Fundamental research in these areas requires the use of cutting-edge technologies and instrumentation, which the INFN develops both in its own laboratories and in collaboration with the world of industry. These activities are conducted in close collaboration with the academic world.

INFN gives employment to about 2000 full time personnel and 3300 associated researcher from the University. Research activity at the INFN is carried out at two types of facilities: the ‘Sezioni’ and the National Laboratories (LNF, LNS, LNL and LNGS). Each of the Sezioni (19) is located at a University Physics Department.

The experiment will be carried out at the Gran Sasso National Laboratory, one of four INFN national laboratories. It is the largest underground laboratory in the world (3 experimental halls with a total volume of about 180,000 m^3) for experiments in particle physics, particle astrophysics and nuclear astrophysics. A first class laboratory for extremely low background experiments. LNGS is recognized by Europe as a large scientific infrastructure. The laboratory is one of the leader participants in the I3 called ILIAS within FP6.

LNGS is used as a worldwide facility by scientists, presently 750 in number, from 22 different countries, working in approximately 15 experiments, each at its own phase of operation. The average 1400 m rock coverage gives a reduction factor of one million in the cosmic ray flux; moreover, the neutron flux is one thousand times less than on the surface, thanks to the low levels of the Uranium and Thorium content of the dolomite mountain rocks. Main research topics of the present programme are: neutrino physics with neutrinos naturally produced in the Sun and in Supernova explosions and neutrino oscillations with a beam from CERN (CNGS program), search for neutrino mass in neutrinoless double beta decay, dark matter search, nuclear reactions of astrophysical interest.

The scientific, technical and administrative structure of the laboratory will provide the perfect place for the location of this experiment. We expect a first class scientific environment and a close competition with other experiments, a theory division that will help us in any calculation, technical services with competences in cryogenics and low radioactivity measurements and we could also count on the excellent outreach division of the laboratory.