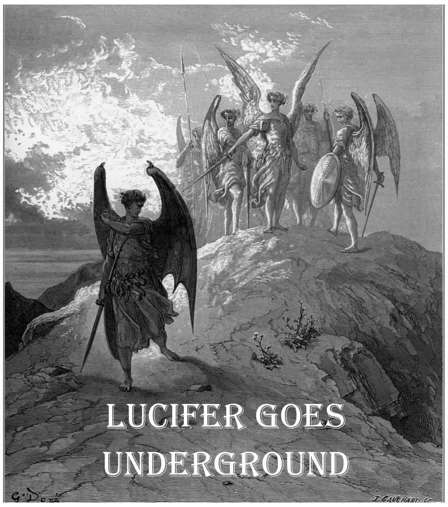
ERC Advanced Grant

Research proposal (B1)

LUCIFER

Low-background **U**nderground **C**ryogenic **I**nstallation **F**or **E**lusive **R**ates

Principal Investigator: Fernando Ferroni
Co-Investigator : Andrea Giuliani
Proposal duration: 60 months
Hosting Institution: INFN- Laboratori Nazionali del Gran Sasso



In the field of fundamental particle physics the neutrino has become more and more important in the last few years, since the discovery of its mass. In particular, the ultimate nature of the neutrino (if it is a Dirac or a Majorana particle) plays a crucial role not only in neutrino physics, but in the overall framework of fundamental particle interactions and in cosmology. The only way to disentangle its ultimate nature is to search for the so-called Neutrinoless Double Beta Decay ($0\nu2\beta$).
The goal of LUCIFER is to build a background-free $0\nu2\beta$ experiment with a discovery potential better than the future, already approved, funded experiments. Although aiming at a discover, in the case of insufficient sensitivity the LUCIFER technique will be the demonstrator for a higher mass experiment able to probe the entire inverted hierarchy region of the neutrino mass and to start approaching the direct one. The idea of LUCIFER is to join the bolometric technique proposed for the CUORE experiment (one of the few $0\nu2\beta$ experiments in construction world-wide) with the bolometric light detection technique used in cryogenic dark matter experiments. The bolometric technique allows an extremely good energy resolution while its combination with the scintillation detection offers an ultimate tool for background rejection. Preliminary tests on several double-beta-decay detectors have clearly demonstrated the excellent background rejection capabilities that arise from the simultaneous, independent, double readout (heat + scintillation).

Section 1a.1: ***The Principal Investigator***

i.1 Scientific Leadership Profile

Summary of Publications

h index = 71

Your result was: **951** [eligible papers = 908 (published or arXiv E-prints)]

Breakdown of search results by citation

	All papers	Published only
Renowned papers(500+ cites):	1	1
Famous papers (250-499 cites) :	7	7
Very well-known papers (100-249) :	21	20
Well-known papers (50-99) :	100	95
Known papers (10-49) :	457	358
Less known papers (1-9) :	278	153
Unknown papers (0) :	44	22
Total eligible papers analyzed:	908	656
Total number of citations:	25713	22728
Average citations per paper:	28	35

Research field and impact

The candidate has operated since the beginning of his career in the field of HEP, collaborating in several experiments where he has given important contributions and has occupied different position of responsibilities.

- *in the ISR experiments R107-R208 :*

  In charge and having performed all alone the calibration of the lead glasses of the calorimeter (thesis work)

- *in the SPS WA18 (CHARM) experiment:*

  Design and construction of the test system for the photon detectors of the scintillator calorimeter

  Leading figure of the beam dump experiment analysis

  Analysis leader of the study of structure functions, co-author of the DFLM parameterization that nicely fitted the W, Z production at SppS (most popular parton densities parameterization at the time, cited 369)

- *in L3 experiment*:

  Responsible for the calibration of the 11000 BGO crystals. The daunting goal of an intercalibration at 0.5% has been achieved.

  Analysis leader of the Z line-shape

  Project leader of the scintillating fiber calorimeter that filled the gap between the BGO barrel and endcaps.

- *in RD22 experiment:*

  demonstration of the possibility to extract, with large efficiency, particles from the halo of the SPS coasting beam through channeling in a bent silicon crystal. The proposal that I presented at the LHCC at the time is now being considered as an option for the collimation of the LHC

- *in BaBar experiment:*

  Project Leader of the Aerogel PID system. This has been the first demonstration on the field of the practical use of HPDs as photon detectors.

Leading figure (member of the steering committee) of the Drift Chamber project. Designed the forward end-plate with minimization of material and proposed, directed the construction and in charge for the operation of the robotic stringing system. The 30000 wires of the chamber were strung (at TRIUMF) in 3 months, with minimal human effort and they operated without a single failure for the 10 year of running of the experiment.

Physics Analysis Coordinator in 1998-1999, at the start of the experiment. Author of the compact Data Format on which the BaBar analyses have been performed for the first 5 years. Responsible of setting up the Analysis (and Physics Tools) Working Group structure that was after maintained for the entire life of the experiment.

Observing at the very beginning of the experiment the inadequacy of the computing model to stay in front of the data rate, I triggered a computing review that brought to a radical change of cap (away from Objectivity based system). At the same time I decided for setting up a crash crunching program that allowed the experiment to present first results at the Stanford Lepton Photon Conference in 1999.

Given the credibility gained in the collaboration, after the disaster of the Resistive Plate Chambers that could have doomed the entire experiment, I was called as System Manager with the task of understanding the problem, devising a solution and implementing it at the fastest pace. The enterprise, that involved reshaping the participation involving US groups beside the Italian ones, was a clear success. The next generation of counters, made with substantial modifications and a strict quality control entirely designed from scratch, lasted with good performances until the end, much improving the PID capability of the experiment. The entire process and the experience gained this way was transferred to LHC experiments that greatly benefited from it.

Member of Technical Board of the experiment

Member of Executive Board of the experiment

Leading figure with his students in several keystone analyses: $\sin 2\beta$ that allowed the discovery of CP-violation, discovery of new families of hadronic resonances, direct CP violation in $B \to K\pi$ decay, measurement of the angle α in $B \to \pi\pi$, observation of D^0 oscillations, introduction of the technique of analyzing the recoil state against a fully reconstructed B (pure B-beam), introduction of the Dalitz analyses in BaBar environment utilized for the studies on the angle γ of the CKM matrix

- *in CUORE experiment:*

  Member of Executive Board of the experiment

  Leader of the TeO_2 crystal project. Together with a material science engineer (later cited for the LUCIFER project) has carried on the negotiation with SICCAS company (PRC), devised the production scheme, agreed on the quality controls for the materials in several labs, the one in-situ for the crystals and finally at LNGS upon their final delivery.

Academic career of students supervised

in CHARM: Sivio Morganti (Primo Ricercatore INFN Roma), Roberta Santacesaria (Primo Ricercatore INFN Roma), Marcella Diemoz (Dirigente di Ricerca INFN Roma)

in L3: Claudia Cecchi (Ricercatore Universitario Perugia), Mario Campanelli (Academic staff at UC London), Simone Paoletti (Ricercatore INFN Firenze)

*in BaBar:*Shahram Rahatlou (Professore Associato Roma), Gianluca Cavoto (Ricercatore INFN Roma), Marco Serra (Tecnologo INFN Roma),Francesco Safai-Teherani (Tecnologo INFN Roma),Daniele del Re (Ricercatore Universitario Roma),Cecilia Voena (Ricercatore INFN Roma), Marcello Rotondo (Ricercatore INFN Padova), Maurizio Pierini (5-year CERN Staff)

the following students have now a PostDoctoral position: Alessia D'Orazio (MPI-Munich), Elisabetta Baracchini (UC Irvine), Francesco Renga (Roma), Viola Sordini (ETH Zurich), Francesca Bucci (Firenze), Alessio Sarti (LNF), Luigi LiGioi (CNAF-Bologna), Silvia Pisano (LAL-Orsay), Antonino Sergi (Perugia), Emanuele di Marco (Roma), Elisabetta Prencipe (Annecy), Francesca Pastore (CERN)

in CUORE: Fabio Bellini (Ricercatore Universitario Roma)

ii.1 Curriculum Vitae

Fernando Ferroni

- Born in Roma, Italy, on January 12, 1952
- Nationality: Italian

- Mailing Address: Dipartimento di Fisica
  Sapienza Università degli Studi di Roma
  P.le Aldo Moro 2,
  I-00185 Roma, Italy

- Education: Laurea in Fisica, Università degli Studi di Roma "La Sapienza" (1974)

- Academic Career:
  2000 - present Professor, Sapienza Universita' di Roma , Roma
  1998 - 1999 Visiting Scientist, SLAC, Stanford, USA
  1992 - 1999 Associate Professor, Universita' di Roma ``La Sapienza'', Roma
  1991 - 1992 Visiting Scientist, CERN , Geneva, Switzerland
  1988 - 1991 Associate Professor, Universita' di Ancona, Ancona
  1982 - 1988 Assistant Professor, Universita' di Roma ``La Sapienza'', Roma
  1977 - 1982 Research Associate, INFN-Roma

Research Activity Summary

1974-1979 R107-R208 experiment at CERN-ISR:
In charge of the lead glass calibration. Search for resonances decaying in two photons. Single gamma production analysis.

1979-1988 WA18 (CHARM) Experiment at CERN SPS:
Scintillator calorimeter construction. Streamer tube upgrade. Analysis of beam dump experiment. Leading role in the study of nucleon structure functions from neutrino scattering with extraction of QCD parameters from Q^2 behavior. Author of a review on nucleon structure functions (Phys Rept. 1986). Author of a parametrization of parton densities for use at collider experiments (DFLM, cited 369), a monography on Neutrino Interactions (in Cambridge Monogr. Part. Phys. Nucle. Phys. Cosmology, 1991) and a textbook for students (together with L. Maiani)

1986-1997 L3 Experiment at CERN LEP:
Responsible of the BGO calorimeter calibration, Analysis of the Z line-shape. Project leader of the scintillating fiber calorimeter construction, installation and operation.

1991-1993 RD22 Experiment at CERN SPS:
Extraction of a proton beam from SPS by a cuved Si crystal by channeling. Presentation of the LHB project to CERN LHCC.

1994- 2008 BaBar Experiment at SLAC:
Design, construction and operation of the BaBar detector Project leader of the Aerogel PID system. In charge of the tooling for robotic stringing of the Drift Chamber. Member of the managemen team of Drift Chamber.. System Manager of the Instrumented Flux Return detector

Physics Analysis Coordinator. Member of the Executive board. Member of the Technical Board. Main results: discovery of CP violation in B-physics , discovery of new families of hadronic resonances , direct CP violation in B-physics , observation of D0 oscillations, discovery of η_b state.

2004-present CUORE Experiment at LNGS:
Neutrinoless Double Beta decay project. Responsible for the TeO2 crystal calorimeter. Member of the Executive Board.

Committees:

2000- 2005 Member of Scientific Committee of Laboratori Nazionali del Gran Sasso- INFN

2001-2004 Member of Large Hadron Collider Committee (LHCC) at CERN

2005-present Member of Modane-Frejus Laboratory Scientific Commiteee

2004-present Chair of Commissione Scientifica Nazionale I of INFN

2008-present Member of the Joint Standing Committee for the China CAS – Italy INFN Virtual Laboratory

2009-present Member of the Scientific Coordination Committee of INFN

Funding ID

Project	**Period**	**Funding Agency**	**Grant (€)**
BaBar (PI of Roma group)	2000-2005	INFN (CSN1)	3148000
PRIN-2003 (RPC studies) (PI of Roma unit)	2003-2004	Italian Ministry of Research	56000
Flavor Physics – Roma Univ. Project (Coord.)	2007	Roma University La Sapienza	41000
CUORE (Coordinator of TeO_2 crystal procurement)	2007	INFN (Executive Board)	2000000
CUORE (PI of Roma group)	2007	Roma University La Sapienza	18900
TOTAL	**2000-2007**		**5263900**

iii.1 10-Year-Track-Record

Top-10 publications ordered according to the number of ISI Web of Knowledge citations

1. The BABAR detector Aubert B et al., NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A- Volume 479 Issue 1 Pages 1-116 , FEB 21 2002
   Times Cited 619
2. Observation of a narrow meson state decaying to D-s(+)pi(0) at a mass of 2.32 GeV/c(2) Aubert B et al., PHYSICAL REVIEW LETTERS Volume 90 Issue 24 Article Number 242001, JUN 20 2003
   Times Cited 327
3. Observation of CP violation in the B-0 meson system Aubert et al., PHYSICAL REVIEW LETTERS Volume 87 Issue 9 , AUG 27 2001
   Times Cited 279
4. Measurement of the CP asymmetry amplitude sin2 beta with B-0 mesons Aubert B et al., PHYSICAL REVIEW LETTERS Volume 89 Issue 20 Article Number 201802 , NOV 11 2002
   Times Cited 236
5. Measurements of branching fractions and CP-violating asymmetries in B-0 ->pi(+)pi(-), K+ pi(-), K+K- decays Aubert B et al., PHYSICAL REVIEW LETTERS Volume 89 Issue 28 Article Number 281802 , DEC 31 2002
   Times Cited 124
6. Observation of a broad structure in the pi(+)pi(-)J/psi mass spectrum around 4.26 GeV/c(2) Aubert B et al., PHYSICAL REVIEW LETTERS Volume 95 Issue 14 Article Number 142001, SEP 30 2005
   Times Cited 120
7. Study of the B- -> J/psi K-pi(+)pi(-) decay and measurement of the B- -> X(3872)K- branching fraction Aubert B et al., PHYSICAL REVIEW D Volume 71 Issue 7 Article Number 071103 , APR 2005
   Times Cited 110
8. Study of time-dependent CP-violating asymmetries and flavor oscillations in neutral B decays at the Upsilon(4S) Aubert B et al., PHYSICAL REVIEW D Volume 66 Issue 3 Article Number 032003, AUG 1 2002
   Times Cited 108
9. Direct CP violating asymmetry in B-0 -> K+pi(-) decays Aubert B , et al., PHYSICAL REVIEW LETTERS Volume 93 Issue 13 Article Number 131801 , SEP 24 2004
   Times Cited 97
10. CUORE A Cryogenic underground observatory for rare events Ardito R, et al., hep-ex/0501010 , JAN 06 2005
    Times Cited 28

(Some of the) Invited Presentations to Conferences, Workshops and Schools

1. "Experimental status of CP violation". Prepared for 9th Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Gravitation and Relativistic Field Theories (MG 9), Rome, Italy, 2-9 Jul 2000 in *Rome 2000, Recent developments in theoretical and experimental general relativity, gravitation and relativistic field theories, Jul. 2000
2. "CPconf2000: A Summary"
   Proceeding of the International Conference on CP Violation Physics, Ferrara Italy, September 18-22, 2000 in NUCLEAR PHYSICS B-PROCEEDINGS SUPPLEMENTS Volume: 99B Pages: 323-330 Published: MAY 2001
3. "Charmless two-body B decays: A way to alpha and gamma". Prepared for QCD@Work: International Conference on QCD: Theory and Experiment, Martina Franca, Italy, 16-20 Jun 2001 in *Martina Franca 2001, QCD@WORK* 153-164

4. CP violation in B-Physics
   Ferroni F , Proceeding of the Vulcano08 Frontier Objects in Astrophysics and Particle Physics Workshop, May 24-29, 2004 in NUOVO CIMENTO DELLA SOCIETA ITALIANA DI FISICA B- Volume: 120 Issue: 6-8 Pages: 615-623 Published: JUN-AUG 2005
5. "Status and perspectives in Italian HEP with accelerators". Prepared for 17th Conference on High Energy Physics (IFAE 2005) Catania, Italy, 30 Mar - 2 Apr 200 in AIP Conf.Proc.794:3-7,2005.
6. "HIF05: Summary". Prepared for High Intensity Frontier Workshop (HIF05), La Biodola, Isola d'Elba, Italy, 28 May - 1 Jun 2005 in Nucl.Phys.Proc.Suppl.154:192-194,2006.
7. CP violation in B-physics". Prepared for International Workshop on Quantum Chromodynamics: QCD@Work 2005, Conversano, Bari, Italy, 16-20 Jun 2005 in AIP Conf.Proc.806:151-163,2006.
8. "CP violation in B-physics". Prepared for 4th International Workshop on Frontier Science, Milan, Bicocca, Italy, 12-17 Sep 2005 in Frascati Phys.Ser.40:115-124,2006.
9. "What are the arguments against future electron positron colliders for flavour physics". Prepared for International Workshop on Discoveries in Flavour Physics at e+ e- Colliders (DIF 06), Frascati, Rome, Italy, 28 Feb - 3 Mar 2006 in Frascati Phys.Ser.41:393-396,2006.
10. "Majorana Neutrinos". Prepared for HQL-2006-034 In the Proceedings of International Conference on Heavy Quarks and Leptons (HQL 06), Munich, Germany, 16-20 Oct 2006.
11. "Future prospects for heavy flavor physics: Round table". Prepared for Workshop on Theory, Phenomenology and Experiments in Heavy Flavor Physics, Capri, Italy, 29-31 May 2006 in Nucl.Phys.Proc.Suppl.163:198-202,2007.
12. "Status and perspectives in B-physics". Prepared for 2nd Cairo International Conference on High Energy Physics (CICHEP 2), Cairo, Egypt, 14-17 Jan 2006 in AIP Conf.Proc.881:203-209,2007.
13. "The Cuore experiment", WE-Heraeus-Seminar: Massive Neutrinos, July 9-12, 2006
14. "CP Violation. State of the Art and Prospects" , in 4th Workshop on the CKM Unitarity Triangle (CKM2006) in Nagoya, Japan, December 12-16, 2006.
15. "The second generation BaBar RPCs: final evaluation of performances", RPC2007: The IX International Workshop on Resistive Plate Chambers and Related Detectors , February 13-16 2008, Mumbai India, in press on NIMA
16. "Challenging the neutrino mass with CUORE", 10th ICATPP Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physics Applications , Villa Olmo, Como, October 8-12, 2007
17. "Neutrinoless Double Beta Decay Searches: Present and Future", Les rencontre de Physique de la Vallee d'Aoste, La Thuile, February 24-March 1, 2008
18. "Present and future of neutrinoless DBD searches", Vulcano08 Frontier Objects in Astrophysics and Particle Physics, May 26-31 2008
19. "Results of Cuoricino and review of neutrinoless double beta searches", Rencontre de Moriond EW 2009, March 7-14, 2009

Membership of Advisory Committee, Organization of conferences, Direction of schools

1. International Advisory Committee (and co-founder together with P. Schlein) Beauty Series (International Conference on B-Physics at Hadron Machines (since 1993)
2. Organization Committee XX International Symposium on Lepton and Photon Interactions at High Energies July 23-28, 2001 Roma
3. International Advisory Committee Frontier Detectors for Frontier Physics, La Biodola (Isola d'Elba) (since 2006)
4. International Advisory Commitee DIF 06 February 28-March 03, 2006 Frascati
5. International Advisory Committee CKM 2008 September 9-13, 2008 Roma
6. Chair of the organization for The Legacy of E. Amaldi in Science and Society Conference October 23-25, 2008 Roma
7. Director of the school Measurement of Neutrino Mass (Course CLXX) at International School of Physics 'Enrico Fermi' , 12-17 June, 2008, Varenna
8. International Advisory Committee WIN 09 September 14-19, 2009 L'Aquila

Section 1a.2: *The Co-Investigator*

i.2 Scientific Leadership Profile

Summary of Publications

h index = 20

155 eligible papers	
Well-known papers (50-99):	3
Known papers (10-49):	26
Less known papers (1-9):	62
Unknown papers (0):	64

Research field and impact

Andrea Giuliani has given incisive contributions to the development of a new class of particle detectors (bolometers). He is and was involved, in prominent positions, in experiments in Astroparticle Physics at Gran Sasso Underground Laboratories, in Como and in Milano cryogenics laboratories (MIBETA, CUORICINO, CUORE, MARE). He is leading a research group involved in low-temperature detector development and neutrino physics at the Insubria University.

In the technological field, he contributed to bring bolometric devices to a very high precision, realizing X- and alpha-detectors with energy resolutions much better than those achievable by conventional instruments. He contributed to the development of the most massive bolometric gamma detectors ever realized. Furthermore, he proposed and realized composite low-temperature calorimeters with sensitivity to surface events.

In the scientific field, he has collaborated and collaborates to various experiments on neutrino physics:

- He participates to **CUORICINO**, one of the most sensitive experiments in the world on Double Beta Decay (giving a limit on Majorana neutrino mass of the order of 0.5 eV), based on bolometric detectors.
- He participates to **CUORE**, one of the most promising new generation experiments for Double Beta Decay. He is member of the Executive Board and of the Technical Board of the CUORE collaboration and leader of the Working Groups concerning the basic detecting element and **CUORE-0**, the first section of the experiment of imminent realization.
- He has been Principal Investigator in the **MIBETA** experiment, funded by INFN and aiming at the determination of the electron antineutrino mass through the spectroscopy of ^{187}Re beta decay.
- He is now promoting a large expansion of the MIBETA experiment (**MARE** project) aiming at a 0.2 eV sensitivity to neutrino mass.

At the University of Insubria, he has funded and he is now coordinating a cryogenic laboratory for the development of bolometers, to be used not only in neutrino physics but also for astrophysical and technological applications.

He has also promoted the realization and the instrumentation of a semi-deep underground laboratory (Baradello hill, Como, Italy) where high precision measurements of trace radioactivity are performed for fundamental research and environmental monitoring.

He is author of about 160 publications in international physics journals and has given numerous invited talks about low temperature detectors of radiation, Double Beta Decay and neutrino mass at international conferences.

He is presently coordinator of a Joint Research Activity inside **ILIAS**, aiming at a European coordination of the Double Beta Decay searches. ILIAS is an Integrating Activity in the VI Framework Programme of the European

Commission, having the scope to structure the European scientific community in Astroparticle Physics and to support the related infrastructures, in particular the underground laboratories. He is coordinating the efforts of the community to re-submit successfully ILIAS in the VII Framework Programme.

He is member of the **Pear Review Committee of ApPEC** (Astroparticle Physics European Coordination), an organism created by the European funding agencies to promote and coordinate Astroparticle Physics in Europe. In this framework, he has actively contributed to the development of the European Roadmap for Astroparticle Physics, taking care of the neutrino-mass section as working group convener.

He is member of the Executive Board of **CELLAR**, an organism which coordinates semi-deep and deep laboratories in Europe for the measurement of low level gamma radioactivity.

Academic career of students supervised

Luca Foggetta (Ricercatore Universitario Insubria – temporary position)
The following students have now a PostDoctoral position:
Marisa Pedretti (Livermore,CA), Samuele Sangiorgio (Madison,WI), Claudia Nones (Insubria), Erica Andreotti (Insubria)
Claudia Nones was approved for a an intra-European Marie-Curie grant funding (Orsay, 2010-2011).

ii.2 Curriculum Vitae

Andrea Giuliani

- Born in Milano, Italy, on March 12, 1961
- Nationality: Italian

- Mailing Address: Università dell'Insubria
  Dipartimento di Fisica e Matematica
  Via Valleggio 11
  22100 Como (Italy)

- Education: PhD in Physics, Università degli Studi di Milano (1989)

- Academic Career:

1999-present	Associate Professor at the Insubria University, Como, Italy
1997	Senior Researcher at INFN, Milano section, Italy
1991	Researcher at the University of Milano, Italy
1989-1990	Post Doc, INFN (Istituto Nazionale di Fisica Nucleare), Milano section, Italy
1986-1989	Ph.D. Student in Physics, University of Milano, Italy
1985	Laurea in Physics, University of Milano, Italy

Research Activity Summary

1985-1989	Ph.D. activity: realization of the first "massive" bolometers
1990-1993	Realization of large mass bolometers for neutrinoless Double Beta Decay
1993-2009	Double Beta Decay experiments based on the bolometric technique (CUORICINO, CUORE)
1996-2001	Dark Matter searches and results with TeO_2 bolometers
1993-2009	Direct measurement of the neutrino mass with the bolometric technique (MIBETA, MARE)

Committees:

2006-present	Member of the Executive Board of CELLAR
2007-present	Member of the Peer Review Committee of ApPEC
2007-2008	Convener of the Working Group "Neutrino Mass" for ApPEC / ASPERA, for the preparation of the European Roadmap of Astroparticle Physics
2008-present	Member of the Scientific Commission "Cryophysics, cryoengineering" of IIR (International Institute of Refrigeration

Funding ID

The following table describes the research funds obtained recently by Andrea Giuliani as PI or as local coordinator of various projects.

Project	Period	Funding Agency	Grant (€)
PRIN-2001 (PI)	2001-2003	Italian Ministry of Research	371849
ILIAS-IDEA (Coordinator)	2004-2009	European Commission (FP6)	1150000
ILIAS-N4 (fund administrator at INFN-MIB)	2004-2009	European Commission (FP6)	66500
ILIAS-N3 (fund administrator at INFN-MIB)	2004-2009	European Commission (FP6)	12550
DERBY (INFN PI)	2003-2005	INFN – CSN5	104500
MIBETA (INFN PI)	2006	INFN – CSN2	60000
PRIN-2004 (PI)	2004-2006	Italian Ministry of Research	514400
PRIN-2006(PI)	2006-2008	Italian Ministry of Research	550800
MARE (INFN PI)	2007-2009	INFN – CSN2	425500
Insubria Excellence Project (Deputy Coord.)	2002-2004	Insubria University	21000
TOTAL	**2001-2009**		**3277099**

iii.2 10-Year-Track-Record

Top-10 publications ordered according to the number of ISI Web of Knowledge citations

1. New experimental results on double beta decay of Te-130
   Alessandrello, A; Brofferio, C; Cremonesi, O, et al.
   PHYSICS LETTERS B Volume: 486 Issue: 1-2 Pages: 13-21 Published: JUL 27 2000
   Times Cited: 75
2. High energy resolution bolometers for nuclear physics and x-ray spectroscopy
   Alessandrello, A; Beeman, JW; Brofferio, C, et al.
   PHYSICAL REVIEW LETTERS Volume: 82 Issue: 3 Pages: 513-515 Published: JAN 18 1999
   Times Cited: 59
3. CUORE: a cryogenic underground observatory for rare events
   Arnaboldi, C; Avignone, FT; Beeman, J, et al.
   NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 518 Issue: 3 Pages: 775-798 Published: FEB 11 2004
   Times Cited: 54
4. First results on neutrinoless double beta decay of Te-130 with the calorimetric CUORICINO experiment
   Arnaboldi, C; Artusa, DR; Avignone, FT, et al.
   PHYSICS LETTERS B Volume: 584 Issue: 3-4 Pages: 260-268 Published: APR 1 2004
   Times Cited: 48
5. New limit on the neutrinoless beta beta decay of Te-130
   Arnaboldi, C; Artusa, DR; Avignone, FT, et al.
   PHYSICAL REVIEW LETTERS Volume: 95 Issue: 14 Article Number: 142501 Published: SEP 30 2005
   Times Cited: 43
6. A calorimetric search on double beta decay of Te-130
   Arnaboldi, C; Brofferio, C; Bucci, C, et al.
   PHYSICS LETTERS B Volume: 557 Issue: 3-4 Pages: 167-175 Published: APR 3 2003
   Times Cited: 39
7. Physics potential and prospects for the CUORICINO and CUORE experiments
   Arnaboldi, C; Avignone, FT; Beeman, J, et al.
   ASTROPARTICLE PHYSICS Volume: 20 Issue: 2 Pages: 91-110 Published: NOV 2003
   Times Cited: 35
8. Present status of MI-BETA cryogenic experiment and preliminary results for CUORICINO
   Pirro, S; Alessandrello, A; Brofferio, C, et al.
   NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 444 Issue: 1-2 Pages: 71-76 Published: 2000
   Times Cited: 32
9. New limits from the Milano neutrino mass experiment with thermal microcalorimeters
   Sisti, M; Arnaboldi, C; Brofferio, C, et al.
   NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 520 Issue: 1-3 Pages: 125-131 Published: 2004
   Times Cited: 26
10. A massive thermal detector for alpha and gamma spectroscopy
    Alessandrello, A; Brofferio, C; Cremonesi, O, et al.
    NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH SECTION A-

ACCELERATORS SPECTROMETERS DETECTORS AND ASSOCIATED EQUIPMENT Volume: 440 Issue: 2 Pages: 397-402 Published: FEB 1 2000
Times Cited: 26

(Some of the) Invited Presentations to Conferences, Workshops and Schools

1. "Particle and Radiation Detection with Low Temperature Devices", invited paper at XXII International Conference on Low Temperature Physics", Helsinki, Finland, 4-11 August 1999
2. "Phonon-Mediated Detectors of Radiation: State of Art", invited paper at SPIE's 46th Annual Meeting International Symposium on Optical Science e Technology, San Diego, California, USA, 29 July - 3 August 2001
3. "CUORE: Low Temperature Techniques for Neutrino Physics", invited paper at XXIII International Conference on Low Temperature Physics, Hiroshima, Japan, 20-27 August 2002
4. "Experimental methods for direct measurements of the Neutrino Mass", Lecture at "International School on AstroParticle Physics", European Doctorate School, Madonna di Campiglio, 14-19 July 2003
5. "Current Double Beta Decay Experiments", invited paper at TAUP2003, Eighth International Workshop on Topics in Astroparticle and Underground Physics, University of Washington, Seattle, Washington, USA, 5-9 September 2003
6. "Low Temperature Detectors: State of the Art" invited paper at 8th ICATPP Conference on Astroparticle, Particle, Space Physics, Detectors and Medical Physics Applications, Villa Erba, Como, 6-10 October 2003
7. "Search for Neutrinoless Double Beta Decay: Present and Future", invited paper at 7-th International Conference on Heavy Quarks and Leptons, San Juan, Portorico, 1-5 June 2004
8. "Low Temperature Detectors For Photon Spectroscopy In Astronomy And Astrophysics", key-note at IEEE Nuclear Science Symposium 2004", 16-22 October 2004, Roma, Italia
9. "Double Beta Decay: future experiments", invited paper at NDM06 The 2nd Symposium On Neutrinos and Dark Matter in Nuclear Physics, Paris, September 3-9, 2006
10. "Dark Matter direct detection", Lecture at the International Doctorate School "The dark side of the Universe", Villa Olmo, Como, May 14-18, 2007
11. "Neutrinoless Double Beta Decay: experimental status", invited paper at Focus Week: Neutrino Mass, IPMU, Tokyo, 17-20 March 2008
12. "Neutrinoless Double Beta Decay: Experimental techniques", Lectures at the "International School of Physics Enrico Fermi", Summer Courses 2008, Villa Monastero - Varenna, Lake Como, June 17-27

Membership of Advisory Committee, Organization of conferences, Direction of schools

1. Organizing Committee, "Physics of Massive Neutrinos – PMN07", Blaubeuren, Germany, July 1 - 5, 2007
2. International Advisory Committee, "Physics of Massive Neutrinos – PMN08" Milos Island, Greece, May 20 - 22, 2008
3. International Advisory Committee, "Neutrinos in Particle, in Nuclear and in Astrophysics", ECT*, Trento, Italy, November 16-21, 2008

Section 1b: ***Extended Synopsis of the project proposal***

Introduction

It is proposed to realize an experiment (named LUCIFER, standing for **L**ow-background **U**nderground **C**ryogenic **I**nstallation **F**or **E**lusive **R**ates) 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 aims to the observation of the neutrinoless double beta decay (0ν2β), a phenomenon hypothesized very long ago but never observed. In case of success, the experiment would demonstrate the Majorana nature of the neutrino mass and would allow at the same time 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 possibly be the best ever set, having ruled out the entire, so-called, 'degenerate' mass region and having 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. The experiment proposed here is based on the combination of know-how and technologies basically proven, thanks mainly to the work of CUORE, Nemo, CRESST and ROSEBUD collaborations, and at the same time call for a jump forward in terms of background reduction (at a level of less than 10^{-3} count/keV/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 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.

Physics Motivation

Measurements with LUCIFER have the potential to fundamentally transform humankind's understanding of elementary particles. A possible discovery of neutrinoless double beta decay would be truly transformational.

The question LUCIFER is addressing is probably the highest priority in neutrino physics today. Were neutrinos found to be Majorana particles it would demonstrate that lepton number was not a fundamental symmetry and possibly even provide a clue as to why the Universe is matter-dominated (rather than an equal mixture of matter and antimatter).

If discovered, 0ν2β could:

- provide an independent verification of the existence of neutrino mass along with a measure of its absolute scale and mass hierarchy;
- establish the nature of the neutrino wherein it is its own antiparticle
- establish the violation of a fundamental symmetry, lepton number conservation.

Given its projected sensitivity down to an average neutrino Majorana mass of approximately 60 meV, the LUCIFER experiment will probably provide the greatest discovery reach of any currently funded 0νββ experiments. The importance of the discovery is however of such a value that a positive result from at least two experiments, performed on different isotopes, will be requested for its validation. The proposed experiment intends to exploit ^{82}Se. Other experiments running at the same time will exploit ^{76}Ge and ^{130}Te.

The Bolometric Technique for Double Beta Decay

LUCIFER will consist of an array of tens of scintillating bolometers, cooled down to ~ 10 mK in an existing dilution refrigerator in LNGS (Gran Sasso underground laboratories), where CUORICINO has been running for five years.

The technology proposed for LUCIFER is mature and safe: initially proposed about 25 years ago, it has lead to the most sensitive 0ν2β experiment ever operated (CUORICINO) and is the basis for one of the most promising future searches (CUORE). The additional tool of scintillation detection is based on the experience gathered in two dark matter searches (CRESST and ROSEBUD) and on a specific R&D for double beta decay.

Bolometers are low-temperature-operated particle detectors which provide better energy resolution, lower energy thresholds and broader material choice than conventional devices. They can be thought as perfect calorimeters, able to thermalize fully the energy released by a particle.

Bolometers consist of two main parts.

- **Energy absorber –** It is the main detector part. The energy deposited by a single quantum into this element determines an increase of its temperature. This temperature variation corresponds to the ratio between the energy released by the particle and the heat capacity of the absorber. Therefore, the main requirement is to operate the device at low temperatures (usually < 0.1 K and sometimes < 0.015 K) in order to make its heat capacity low enough. Another requirement is that the absorber material is dielectric and diamagnetic, assuring a very low specific heat at low temperatures. In the case of LUCIFER, a high mass fraction of the absorber is constituted by a double beta decay candidate.
- **Thermometer –** It is thermally coupled to the energy absorber and measures its temperature. The thermometer is usually a resistive element with a strong dependence of the resistance on the temperature. For large mass bolometers, as in the case of LUCIFER, a reliable and simple thermistor technology consists of the use of neutron transmutation doped (NTD) Ge thermistors.

A very sensitive approach for the study of $0\nu2\beta$ consists in developing a device which is **source and detector** of the phenomenon at the same time.

In this method, the required features of the detectors are the following.

- It must contain the candidate nuclei with a favorable mass ratio and be **massive** (of the order of 100 kg for new-generation experiments).
- It must exhibit **good energy resolution**. This parameter 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.
- It must be characterized by **low intrinsic background**.

Bolometric detection of particles is clearly able to provide all the required features. High energy resolution is one of the characteristic of this technology. The absorber materials are single crystals, which normally are very pure because of the crystallization process itself. The key cryogenic material, usable for the cryostat and the detector holders, is copper, which can be obtained with very high intrinsic radio-purity.

In this sense, bolometers represent the **generalization of the Ge diode technique** to the majority of the interesting candidates.

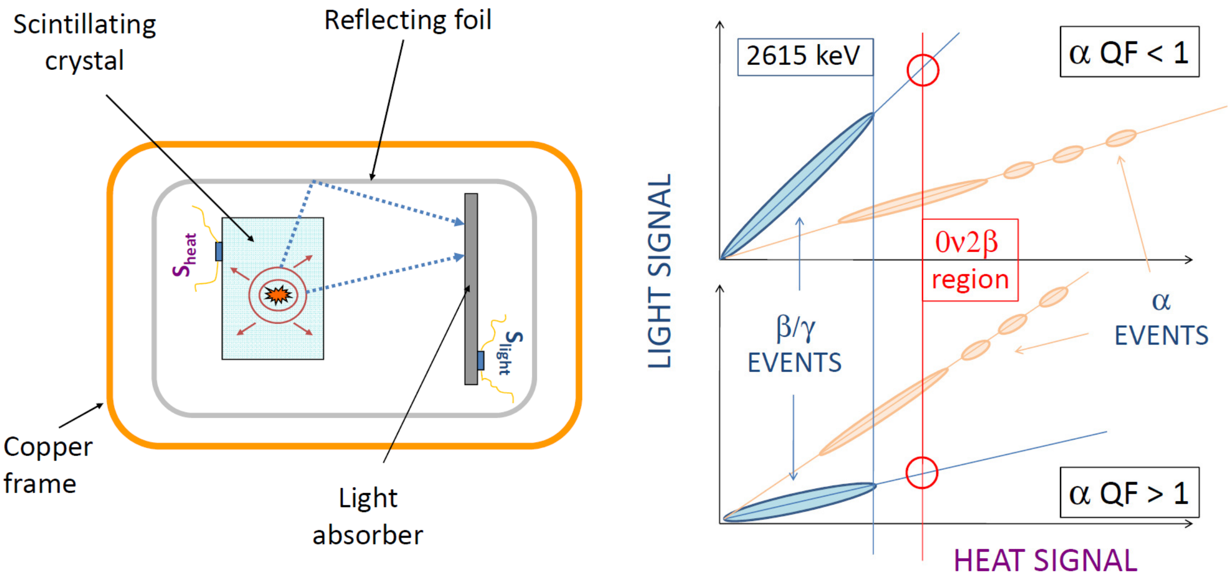
The Additional Value of Scintillating Bolometers for Background Abatement

Up to now, the choice for bolometers as $0\nu2\beta$ detectors 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 candidate ^{130}Te. The success of CUORICINO – presently the most sensitive $0\nu2\beta$ experiment together with the controversial Heidelberg-Moscow search – and the excellent prospects for CUORE are based on this approach.

There are very good arguments which show how CUORE can be defined as an observatory for the bolometric search for $0\nu2\beta$. 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. Both from the point of view of background and decay rate, a detector based on a double beta decay emitter with a Q-value above the 2615 keV line of ^{208}Tl represents the optimal starting point for a future experiment. High Q-values imply large phase space for the decay (growing as ~ Q^5) and signal out of almost the entire region of the natural gamma radioactivity.

In LUCIFER, it is proposed to use **scintillating bolometers** to the search for $0\nu2\beta$ in high Q-value candidates: the added value brought by scintillation is enormous.

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. In particular, alpha particles can be discriminated with respect to beta and gamma interaction because of the different quenching factor (QF). Therefore, the ratio of the light-to-heat yield of an alpha particle is well different from that of an electron or gamma. The scheme below illustrates the concept of the detector (left) and of the analysis (right).



The ability to **tag alpha particles** is a formidable asset in the search for 0ν2β 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 0ν2β candidates. Hence, the power of scintillating bolometers, with their efficient α/β discrimination.

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.

Several compounds were successfully tested as scintillating bolometers containing a high mass fraction of a high-Q-value 0ν2β candidate: $CdWO_4$, $CdMoO_4$ (for ^{116}Cd), $PbMoO_4$, $CaMoO_4$, $SrMoO_4$, $SrMoO_4$, $ZnMoO_4$ (for ^{100}Mo); CaF_2, $CaMoO_4$ (for ^{48}Ca) and ZnSe (for ^{82}Se). The preliminary results show that best candidates are **$CdWO_4$**, **$ZnMoO_4$** and **ZnSe**.

This last compound was extensively analyzed in dedicated R&D program. One of its most striking features is the abnormal alpha QF, higher than 1 unlike all the other studied compounds. Although not really welcome, this unexpected property 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. An additional very useful feature is the possibility to perform α/β discrimination on the basis of the temporal structure of the signal.

A preliminary analysis suggests an alpha-rejection efficiency better than 99% 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 in CUORICINO and CUORE R&D, can then be reduced down to ~ 10^{-3} counts/keV/kg/y and below.

LUCIFER Structure and Sensitivity

The sensitivity study of a future 0ν2β experiment with scintillating bolometers has been performed with the assumption to exploit fully the experimental volume of the existing (and available) cryostat used for CUORICINO. A baseline version consists of an array of 48 crystals, divided in 12 elementary modules of 4 crystals each and stacked as to form a tower. The total active volume will be: $V = N_{cry} \times V_{cry} = 48 \times 125\ cm^3 = 6000\ cm^3$ (assuming crystals of $5 \times 5 \times 5\ cm^3$ as in CUORICINO).

When applying different materials to this scheme and considering all the relevant elements (scientific, technical, economical), **the final balance is in favour of ^{82}Se (ZnSe crystals)**. The cost is affordable in the experiment budget (1.2 M€ for the baseline option, taking the average of the price fork with 20% uncertainty at this point), and a 1 σ sensitivity in the range ~ 50-70 meV can be obtained.

The detector configuration proposed for LUCIFER resembles closely the one selected and extensively tested for CUORE, with an **additional light detector**, designed according to the recipes developed during the scintillating-bolometer R&D and **consisting of an auxiliary bolometer**, opaque to the light emitted by the ZnSe crystals.

This choice minimizes the amount of work necessary to set up the detector structure. The LUCIFER elementary module will contain **five bolometers**:

- **Four ZnSe cubic 5-cm-side crystals** will be arranged in each module. One NTD Ge thermistor will be glued on each crystal.
- The elementary-module holder is designed so as to house in its upper part 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 Si slab is placed above the ZnSe crystals. Again, an NTD Ge thermistor and a heater will be glued on the Si slab.

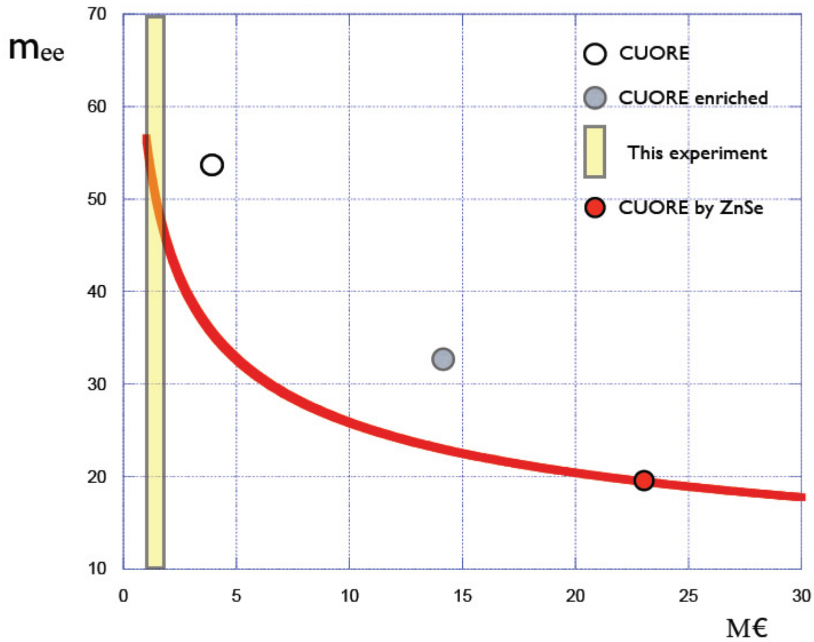
This configuration allows the light detector to see the four crystals underneath, and to offer its upper face to the adjacent elementary module with its four ZnSe crystals.

The elementary modules described above will be stacked so as to form a tower. The sequence will start from below with an isolated light detector. Then, 12 elementary modules will be assembled one above the other. The tower will fully exploit the available space in the CUORICINO cryostat, given the present configuration of the internal lead shielding. In the baseline options, the **total bolometric mass will be 31.7 kg**, and the corresponding **mass of the enriched material 17.6 kg**. Other two viable options (more expensive but possibly affordable in the range of cost known for Selenium enrichment) are taken into consideration. They could bring the mass of the enriched material to **20.5 and 27.8 kg**.

International Context and Competition

There are several ongoing projects for 0ν2β 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 3σ 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 0ν2β 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.