

The MAYORANA Project

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A multidisciplinary networking on neutrino physics for exchanging knowledge and expertise and founding a scientific common field and a high educational international School is the multi-purpose goal of the MAYORANA (MultidisciplinArY netwORking Approach on Neutrino Aspects) Project. The neutrino is a key particle for astroparticle, particle and nuclear physics. At the current state-of-the-art, the nuclear and astro/particle communities, operating independently in neutrino physics, can play a real key role providing they merge own knowledge and expertise. In the scientific community of Catania (Italy), we identify different astro/particle/nuclear experiments (AUGER, ICARUS/DUNE, JEM-EUSO/POEMMA, JUNO, KM3NeT, NUMEN) active in the field. We intended to explore scientific synergies among local research groups for initiating a local networking, foster international networking with related world-wide groups, integrate local expertise on related experimental and data analysis techniques, organize an international two-years High Educational School on Neutrino Physics, characterized by a multidisciplinary approach, by merging nuclear, particle and astroparticle aspects. The fundamental result has been the foundation (2023 First Edition) and the organization of the international MAYORANA (Multi-Aspect Young-ORiented Advanced Neutrino Academy) SchoolWorkshop, based in the Sicilian territory, with relevant social, cultural, scientific and educational outcomes. On the basis of the real and recognized success of the First Edition, the Second Edition of this School has taken place in June 2025. Here, we will describe genesis, steps and efforts, educational results and outreach outcomes of that novel venture.

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1. General description and purposes

The neutrino (ν) is a key elementary particle for astroparticle, particle and nuclear physics. A very elusive particle having only a weak charge, no electric charge and colour charge, its interactions with nuclei are extremely weak and experimental studies very hard. Its existence was postulated by W.Pauli in 1930 [2] to explain the continuous spectrum of β -decay [1]; named as *neutrino* by E.Fermi in 1932 [3], was experimentally discovered only in 1956 by C.Cowan and F.Reines [4] in experiment with a nuclear reactor. The ν arising in a nucleus, was initially investigated in nuclear physics; with the fast and lively discovery of elementary particles, firstly in experiments investigating cosmic rays (1930 ÷ 1950) and then using accelerators, and the spectacular success of the Standard Model of Particle Physics, the search for ν properties became a particle physics's prerogative and later an astroparticle physics's science case, splitting from the nuclear physics definitively. Nowadays, the ν properties (Dirac or Majorana particle, oscillation phenomena, mass hierarchy, solar- ν fluxes, SuperNovae ν s, High-Energy cosmic ν s are investigated by detecting them from natural (Early Universe, extra-galactic objects, SNs, Sun, terrestrial atmosphere, Earth) and artificial (accelerators, reactors, radioactive materials) sources in a wide energy range. In any case they are detected experimentally through ν -related weak processes in nuclei (single β , inverse β , neutrino-less double β decays, electron capture) so that nuclear responses are again crucial. In spite of several experiments over years, some fundamental ν properties are still not well understood and many questions are still unsolved. At the current state-of-the-art, two existing, but also separated, scientific communities (astroparticle/particle & nuclear) could play a key role in exploring wide-ranging the ν properties by merging knowledge and technical expertise for addressing an overview by different and also complementary view-points. In the recent years, a pressing requirement is disseminating in the scientific environment: to find connections among ν communities and re-unify physical (particle & nuclear) aspects, remained distinct for a long time. In that world-wide scenario, in Catania (Sicily region, Italy), where the University of Catania (**UniCT**), and its Department of Physics and Astronomy "Ettore Majorana" (**DFA**), the National Institute of Nuclear Physics (**INFN**) and its Division of Catania (**INFN-CT**) and National Laboratories of the South (**INFN-LNS**), and the Sicilian Center of Nuclear Physics and Physics of Matter (**CSFNMS**) coexist, we identify a high fertile land for merging knowledges among particle, astroparticle, particle and nuclear physics in investigating for ν properties. In addition, a favourable local hystoric context, in terms of important scientific personalities, represents also the foundation of this joint venture: the persons of Prof. Ettore Majorana and the Prof. Giovanni Pietro Grimaldi, both of them with sicilian origins. Ettore Majorana (born in Catania, Sicily-Italy, August 5th, 1906; disappeared March 26th, 1938) [fig.1, on the left] was an outstanding Italian theoretical physicist, who worked on neutrino masses and its properties, student of Prof.Enrico Fermi (September 29th 1901, Rome-Italy; November 28th 1954, Chicago-USA), Nobel Prize in Physics (1938), with the so-called *Guys of Via Panisperna* [fig.1, in the middle]. Giovanni Pietro Grimaldi (October 28th 1860; September 1st 1918, Modica(RG), Sicily-Italy) [fig.1, on the right] was an Italian experimental physicist, Rector of University of Catania (1905-1908), who died without any hear and donated all his property with the aim of social advancement and cultural and scientific promotion by way of a foundation established to his name, the **Fondazione Grimaldi**, with registered office in Modica (RG), Sicily and at present associated with the University of Catania.

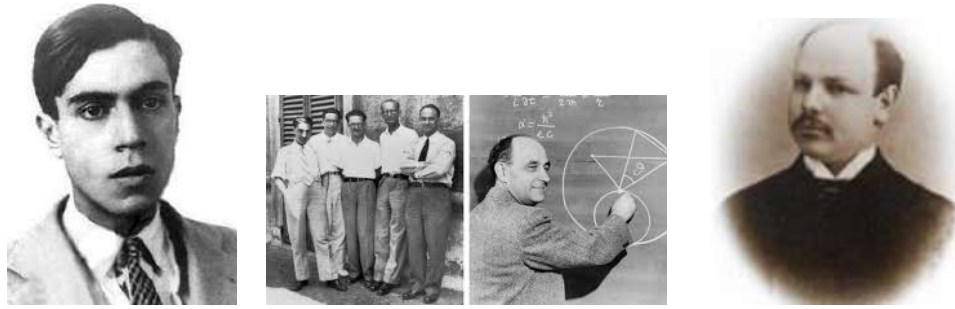


Figure 1: Left: Prof. Ettore Majorana, physicist born in Catania (Italy); middle, left: the "guys of Via Panisperna", middle, right: Prof. Enrico Fermi, Nobel Prize in Physics (1938); right: Prof. Giovanni Pietro Grimaldi, physicist, late Rector of the University of Catania.

Moreover, currently, also a propitious local scientific context is present. Relevant international experimental activities, as yet totally uncorrelated, are locally operating: search for High-Energy ν s (HE ν s) in astroparticle physics, by means of under-water experiments (**KM3NeT Consortium** [5]), ground-based experiments (**Pierre Auger Observatory** [6]) and space-based missions (**JEM-EUSO Program** [7] and the future **POEMMA mission** [8]), study of ν oscillations and properties in particle physics by means of long-baseline experiments from accelerators (**ICARUS experiment** [9] and the future **DUNE Project**[10]) and short-baseline experiments from nuclear reactors (**JUNO Observatory** [11]), measurements of cross sections for double charge exchange nuclear reactions of interest for neutrino-less double β decays ($0\nu\beta\beta$) in nuclear physics by means of nuclear experiments (**NUMEN experiment** [12]). The birth of a multidisciplinary networking on ν physics for exchanging scientific knowledge (**WP1 - Science**) and technical expertise (**WP2 and WP3 - Technology**) and renewing the foundation of an international high educational School (**WP4 - High Education**) is the fundamental goal of this collaborative and manifold effort, named **MAYORANA** (*MultidisciplinArY netwORking Approach on Neutrino Aspects*) Project, in honour of Ettore Majorana by using his surname, specifically modified (with the j letter replaced by the y letter), as an acronym recalling the main features of the Project (see section 2).

2. The MAYORANA Project

In 2020 the University of Catania launched an innovative program of incentives for the academic research, named **PIA.CE.RI**. (*PIA*no di in**CEN**tivi per la **RI**cerca di Ateneo) **Linea 2-2020-2022** by means of a competitive Call for Projects to be supported by public funding after their approval. In particular, the University of Catania encouraged to create collaborations and synergies among distinct research groups from various research institutions and/or different departments operating in Catania. We (the **MAYORANA Team**), signers of this Proceeding, professors and researchers in neutrino physics coming from different scientific (astro/particle and nuclear) domains, decided to apply to the above-mentioned Call in order by presenting our joint venture concerning a network on neutrino physics. The MAYORANA Project (Principal Investigator: Rossella Caruso) was born and the Project was submitted. It was approved and received dedicated funds for two years. The Program was periodically subject to a peer-reviewed process by an external scientific panel in order to check the achievement of milestones. In 2024, the University of Catania launched again the

second edition of that Program (**PIA.CE.RI. Linea 1-2024-2026**) and the MAYORANA Team (Principal Investigator: Rossella Caruso) submitted again the MAYORANA Project with the aim to prolong it. The second edition of the MAYORANA Project was again approved by getting funds for the successive two years. In July 8th, 2024, the University of Catania organized an important and successful public event, named *PIA.CE.RI. DAY 2024* located in Catania, where all the approved and funded PIACERI Projects presented the achieved results by means the exhibition of thematic stands or posters to an open public (fig.??). The MAYORANA Project has been organized (fig.2, left) in main Working Packages (WPs), representing the different goals (see section 1) to be addressed by way of different preparatory actions and concrete steps, described as follows:

- **WP1 - Science**, with the aim of enlarging scientific synergies among local members of ν scientific communities to support a local networking for integrating different know-hows by distinct research groups and sharing own scientific knowledges; in the first stage, moving towards seminar or round tables on a monthly base. The consequent aim is fostering strong international networking with other world-wide groups active in the ν field by organizing workshops on a four-monthly base and inviting colleagues and experts coming from around the world.
- **WP2 - SiPM Technology**, with the aim of integrating local expertise in the development of related experimental techniques, specifically on the Silicon Photo-Multipliers (SiPMs) as innovative photo-detectors for their use under extreme and unusual conditions, such as nuclear reaction experiments performed at high beam intensities (NUMEN), operations under harsh radiation and large temperature ranges in space-base missions (JEM-EUSO), extraordinary states in under-water (KM3Net) environment; functioning at very low temperatures in short-(JUNO) and long-(ICARUS) base-line experiments. That goal can be pursued through the co-sharing of an interdisciplinary local Laboratory for Research & Development on SiPMs . The co-shared Laboratory could be also used for the educational training of high school students by organizing specific hand-on stages and outreach events (Open-Days in Laboratory);
- **WP3 - ML Technology**, with the aim of applying Machine Learning (ML) techniques to the big amount of experimental data acquired from local neutrino experiments and organizing specific seminars and tutorials, addressed to young researchers, Ph.D. students and Master's Degree students.
- **WP4 - High Education**, with the aim of organizing an international high educational School with the main objective of promoting a collaborative world-wide framework of young researchers and brilliant students in the ν field to discuss theories and experiments through interdisciplinary approaches.

3. The international high educational MAYORANA School&Workshop

The main objective of the WP4-High Education in the framework of the MAYORANA Project is to promote a collaborative framework of young and senior researchers from the fields of astroparticle, nuclear and particle neutrino physics to discuss theories and experiments in which interdisciplinary aspects are particularly relevant. The basic idea is to organize a double joint event (an international high educational School and a subsequent international scientific Workshop to be hosted in a particular location: at the historical Palazzo Grimaldi (fig.3, middle), past property of G.P. Grimaldi and at present headquarters of the Fondazione Grimaldi, in the wonderful baroque town of Modica (Sicily, Italy). The School (Chairs: Prof. F. Cappuzzello and Prof. R. Caruso) is

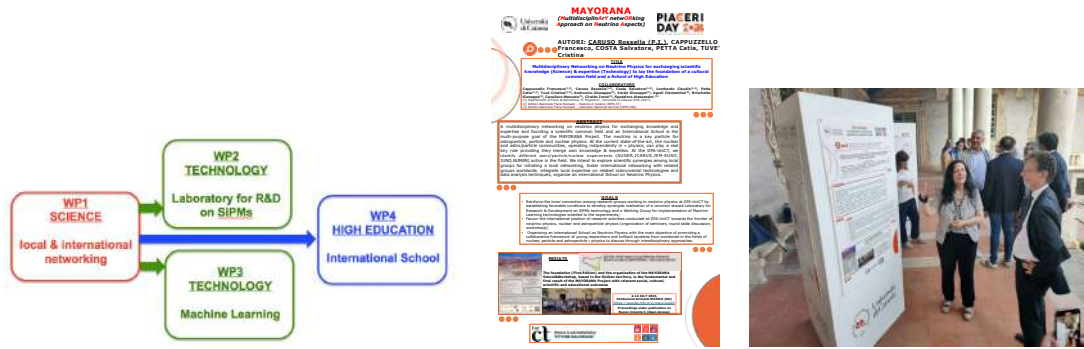


Figure 2: Left: the structure in Working Packages of the MAYORANA Project; middle: the poster representing the MAIORANA Project exhibited during the PIACERI DAY 2024, public event organized by the University of Catania; right: the MAYORANA P.I. shows the MAYORANA Project to the present Rector of the University of Catania, Prof. Francesco Priolo, physicist.

addressed to doctoral students, post-doctoral fellows and young researchers from world-wide and is limited to 50 participants. Specifically for the foundation of the MAYORANA SchoolWorkshop, the acronym has been properly fitted to the goals of the School&Workshop as *Multi-Aspect Young-ORiented Advanced Neutrino Academy*. In addition, a symbolic logo was created (see fig.3, on the left): the triangular outline of Sicily island, where each side has a different colour that converting into another one at each vertex for representing the oscillation phenomenon among the three different neutrino flavours (ν_e , ν_μ and ν_τ) with the ν symbol geographically centered in Modica town. The School activities consist of about 40 hours organized in lectures (fig.3, right) with duration of 2 hours over 6 days. A certificate of attendance is released at the end of the School. Face-to-face discussions with the professors are highly recommended and conducted in an informal atmosphere. In addition, dedicated sessions are organized for the exhibition of posters prepared by the students and special sessions are devoted to oral presentations (named *miniTalks*) by the students. *Question time* and *Round-Table* meetings among professors and students are also arranged. Moreover the students are also to attend the following Workshop, gaining the opportunity to know about most advanced studies in the field directly from the experts. The contents of all the mini-Talks and/or posters presented during the School are published, after a peer review process, as indexed articles on a scientific journal. The Workshop (Chairs: Dr. C.Agosi and M.Cavallaro) takes place just after the School. The aim is to connect researchers from different communities in order to discuss recent results and challenges of modern neutrino physics. The MAYORANA School&Workshop is jointly organized and supported by the University of Catania (**UniCT**), and its Department of Physics and Astronomy "Ettore Majorana" (**DFA**), the National Institute of Nuclear Physics (**INFN**) and its Division of Catania (**INFN-CT**) and National Laboratories of the South (**INFN-LNS**) and the Sicilian Center of Nuclear Physics and Physics of Matter (**CSFNMSM**), with the patronage of the European Physics Society (**EPS**), Italian Physics Society (**SIF**), CSNFNSM and the **Chamber of Deputies** of the Italian Parliament and the sponsorships of ERC-NURE Project [13], **CAEN** Electronics Company, **Consorzio Cioccolato di Modica IGP**. Special prizes are awarded to the best mini-Talk and best Poster presented or exhibited during the School by the students, thanks to the support of CSFNMSM, EPS and CAEN. A rich program of social activities is also organized and offered to the participants during the School&Workshop: guided walking tours along Modica histor-

ical center, visit at the Museum of the Modica chocolate (typical and unique homemade chocolate), excursions to the cities and surroundings of the Val di Noto, the sicilian baroque region declared as UNESCO site; tastings of Modica chocolate & sicilian wines, two different social dinners based on typical sicilian cooking, etc. A public lecture on neutrino physics and a related outreach event, hosted in the main theatre of Modica city and open to the whole citizenry, is organized with the participation of the most important political, institutional and scientific authorities.



Figure 3: Left: the logo of the MAYORANA SchoolWorkshop; middle: the Palazzo Grimaldi in Modica, location of the MAYORANA School&Workshop; right: students attending lectures.

[-] First Edition of the MAYORANA School&Workshop

The foundation (First Edition) and the organization of the international high educational MAYORANA School&Workshop, based in the sicilian territory, is the fundamental and final result of the MAYORANA Project (PIA.CE.RI. Program - first edition) with relevant social, cultural, scientific and educational outcomes. Detailed information about the format, the scientific objectives and its organization are found at the URL: <https://agenda.infn.it/e/mayorana23>. Two main committees were established to coordinate and organize the event: a selected International Advisory Committee (IAC), composed by outstanding scientists in neutrino physics from eminent institutions of different Countries in the world, and a Local Organizing Committee (LOC), formed by the MAYORANA Team. The MAYORANA 2023 event took place in Modica (Ragusa) at the Palazzo Grimaldi since July 4th to July 14th, 2023. It attracted top level scientists, young researchers and students from all over the world, triggering important synergies among University of Catania, INFN, Fondazione Grimaldi, Municipality of Modica and all the institutions, organizations and sponsors involved, also obtaining the high patronage of the italian Chamber of Deputies and the visit of a Minister of the italian Government. The School was addressed to young researchers and brilliant students keeping its international character. About 30 students attended the First Edition of the MAYORANA School&Workshop and 10 professors were invited, based on the recommendation of the IAC; about 100 participants from 10 different Countries in the world attended overall the MAYORANA 2023 event. As deliverables, the proceedings of posters and miniTalks presented by the students, the didactic material shown by the professors and the talks and/or posters presented by the experts during the Workshop was collected, revised and published as *Proceedings of the MAYORANA School&Workshop - First Edition on Il Nuovo Cimento C–Colloquia and Communications in Physics*, a peer-reviewed, open-access, indexed journal published by the SIF [14].

[-] Second Edition of the MAYORANA School&Workshop

The organization (Second Edition) of the international high educational MAYORANA School &Workshop, still based in the sicilian territory, is the fundamental and final result of the MAYORANA Project (PIA.CE.RI. Program - second edition), after the recognised success of the First Edition. Detailed information about the format, the scientific objectives and the organization of the second edition are found at the URL: <https://agenda.infn.it/e/mayorana2025>. On the occasion of the second edition, a Program Committee, composed by academic and researcher staff members of the MAYORANA Team with the responsibility of the scientific program, and a Secretary have been added to the IAC and LOC. The MAYORANA 2025 event took place in Modica (Ragusa) at the Palazzo Grimaldi during the period of June 16th to June 25th, 2025. About 50 students attended the Second Edition of the MAYORANA School&Workshop and 10 professors were invited; more than about 100 participants from 16 different Countries in the world attended overall the MAYORANA 2025 event. The contents of lectures, poster and miniTalks presented in the School and the talks and posters presented in the Workshop will be published as *Proceedings of the MAYORANA School&Workshop - Second Edition* on the Nuovo Cimento C again.

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Figure 4: Left:poster of the First Edition (2023) of MAYORANA School&Workshop; middle:poster of the Second Edition (2025); right:group photo of participants at the MAYORANA School&Workshop 2025.

4. Outcomes and future perspectives

A multidisciplinary networking on neutrino physics for exchanging knowledge and expertise and founding a scientific common field and an international high educational School is the multi-purpose goal of the MAYORANA (MultidisciplinArY netWORking Approach on Neutrino Aspects) Project, funded mainly by an innovative program of incentives for the academic research by the University of Catania. The objectives of the MAYORANA Project contribute towards six (in particular: n.4) Quality Education, n.5) Gender Quality, n.8) Decent Work and Economic Growth, n.9) Industry, Innovation, Technology and Infrastructure, n.16) Peace, Justice and Strong Institutions and n.17) Partnership for the Goals) out of the seventeen Sustainable Development Goals (SDGs)–AGENDA 2030, a set of 17 global goals adopted by the United Nations in 2015 to address pressing global challenges and achieve a more sustainable future for all by 2030. The fundamental result of the MAYORANA Project has been the foundation (2023, First Edition) and the organization

of a successive edition (2025, Second Edition) of the international MAYORANA (Multi-Aspect Young-ORiented Advanced Neutrino Academy) School&Workshop, based in the sicilian territory, with very relevant social, cultural, scientific and educational outcomes. In the course of two edition, the number of attending students has almost doubled, the number of organizing and supporting organizations, institutions and sponsors has increased and a virtuous synergy among different scientific communities in the neutrino field is born and has been reinforced opening strong perspectives for the future and, in particular, with the goal of turning the MAYORANA School&Workshop into a traditional and consolidated appointment in the international scientific landscape.

Acknowledgments

The foundation of the MAYORANA School&Workshop (First Edition, 2023) and the organization of the successive MAYORANA School&Workshop (Second Edition, 2025) could not be possible without the funds assigned to the MAIORANA Project by the University of Catania thanks to the **PIA.CE.RI. (PIA**no di in**CE**ntivi per la **RI**cerca di Ateneo) **Linea 2-2020-2022 Program** and the **PIA.CE.RI. Linea 1-2024-2026 Program** and without the Fondazione Grimaldi. The MAYORANA Team thanks also the contributions and supports, in alphabetic order, of the CSFNSM, DFA, EPS, ERC-NURE, INFN, INFN-CT & INFN-LNS, SIF and the commercial sponsors CAEN and Cioccolato di Modica IGP.

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