

GRUPPO DI RICERCA

Theoretical Nuclear Physics and Quantum Computing

1. DATI IDENTIFICATIVI DEL GRUPPO DI RICERCA

Categorie ERC	PE2
Settore Scientifico Disciplinare	PHYS02
Parole Chiave (Keywords)	Theory of nuclear structure, electroweak decays, quantum computing

2. COMPOSIZIONE E COORDINAMENTO

Responsabile Scientifico / Coordinatore:

- **Nome e Cognome:** Luigi Coraggio
- **Qualifica:** Professore Ordinario
- **Email:** luigi.coraggio@unicampania.it
- **Link Orcid Personale** <https://orcid.org/0000-0002-4327-9107>

Componenti del Gruppo:

(Elencare docenti, ricercatori, assegnisti e dottorandi)

1. **Nunzio Itaco** – Professore Ordinario, <https://orcid.org/0000-0002-9508-2613>
 2. **Giovanni De Gregorio** – Ricercatore a tempo determinato, (art. 24 c.3-b L. 240/10)
<https://orcid.org/0000-0003-0253-915X>
 3. **Davide Marro** – Dottorando del XLI ciclo del Dottorato in Matematica, Fisica e Applicazioni dell'Ingegneria, <https://orcid.org/0009-0008-2517-517X>
 4. **Gennaro Nunziata** – Dottorando del XLI ciclo del Dottorato in Matematica, Fisica e Applicazioni dell'Ingegneria, <https://orcid.org/0009-0002-4862-8844>
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3. ATTIVITÀ SCIENTIFICA E NETWORK

Breve Descrizione delle linee di ricerca:

1. Theoretical Nuclear Physics:

- Nuclear structure calculations with realistic potentials:
The Nuclear Theory group has a long-standing experience in nuclear structure calculations performed through realistic potentials. More precisely, during last years we have worked extensively on the problem of constructing effective shell-model Hamiltonians and decay operators from realistic potentials within many-body perturbation theory, and on their assessment for nuclear structure calculations. Recently, our interest has been focused on two main aspects which are strictly connected to these themes:
 - a. derivation of the effective shell-model Hamiltonian from chiral potentials including three-body components;
 - b. derivation of effective shell-model decay operators to investigate the well-known problem of the *quenching* of the axial coupling constant for nuclear structure calculations of Gamow-Teller transitions.

- Study of electroweak decays

The search of neutrinoless double-beta ($0\nu\beta\beta$) decay is the key to improve our knowledge of the properties of neutrinos and shed light on the limitations of the Standard Model. The rate of this decay is ruled by both the unknown neutrino effective mass and the nuclear matrix elements $M^{0\nu}$ associated with the $0\nu\beta\beta$ transition. $M^{0\nu}$ cannot be measured, hence the success of the experimental programs depends on their accurate theoretical prediction.

During last years, our group has pursued a microscopic framework to the calculation of $M^{0\nu}$ within the realistic shell-model, namely deriving effective shell-model Hamiltonians and β -decay operators from realistic nuclear forces. To validate our approach, we have first calculated nuclear matrix elements $M^{2\nu}$ of the two-neutrino double-beta ($2\nu\beta\beta$) decay for nuclei of current interest for experimental collaborations – ^{48}Ca , ^{76}Ge , ^{82}Se , ^{100}Mo , ^{130}Te , and ^{136}Xe - to test the reliability of our predicted wave functions, then also $M^{0\nu}$ have been calculated for the same nuclei.

In a near future, we are going to approach this subject by employing many-body meson-exchange currents that can be derived within the chiral perturbation theory consistently with the starting nuclear Hamiltonian.

2. Quantum Computing:

Quantum computing has the potential to enhance computational efficiency beyond classical approaches. Our research focuses on developing noise-resilient algorithms and hybrid quantum–classical strategies tailored for realistic quantum devices.

- Nuclear many-body physics

We investigate quantum approaches to the eigenvalue problem of nuclear Hamiltonians. Within the Equation of Motion Phonon Method (EMPM), we reformulate the ground-state problem as a Quadratic Unconstrained Binary Optimization (QUBO) task, paving the way for implementations on quantum annealers.

- Quantum Machine Learning and Quantum Image Processing.

We develop hybrid architectures combining variational quantum circuits with classical optimization. Our work includes edge detection based on a Quantum Fuzzy Inference Engine and hybrid quantum–classical lookup table strategies, as

well as image classification models benchmarked against classical neural networks. Results demonstrate comparable performance to state-of-the-art classical methods while reducing quantum resource requirements, contributing to the assessment of practical quantum advantage in real-world applications.

[Spazio per la descrizione: inserire qui una sintesi degli obiettivi scientifici, delle metodologie e delle principali sfide affrontate dal gruppo. Max 1500 caratteri, per linea di ricerca. Max 3000 caratteri totali.]

Collaborazioni Nazionali ed Internazionali:

(Indicare Università, Enti di ricerca o Aziende con cui si hanno progetti o pubblicazioni in comune)

- **Nazionali:** Istituto Nazionale di Fisica Nucleare (INFN), Università degli studi di Napoli “Federico II”, Università di Pisa, Università del Salento, Università degli studi di Milano-Bicocca
- **Internazionali:** Washington University in Saint Louis (USA), Peking University (People’s Republic of China), Kyushu University (Japan), Charles University (Czech Republic)

4. PROGETTI, BREVETTI E PUBBLICAZIONI

Principali Progetti di Ricerca e Brevetti:

(Indicare i principali progetti di ricerca e gli eventuali brevetti depositati/ottenuti)

- **Calcolo Quantistico Applicato all’Intelligenza Artificiale** - PON Ricerca e Innovazione 2014-2020 – PI: [Luigi Coraggio](#) – 2022-2024 – concluso
- **Technologies for Quantum Computing (TQC)** – Università della Campania “Luigi Vanvitelli” – PI: [Giovanni De Gregorio](#) – 2022-23 – concluso
- **Exploiting separation of scales in nuclear structure and dynamics** – PRIN 2022 - responsabile dell’unità locale Università “Luigi Vanvitelli”: [Luigi Coraggio](#) – 2023-2026 - concluso
- **Quantum Machine Learning Algorithms for Nuclear Theory and Edge Detection (QML-NTED)** – PNRR – PI: [Luigi Coraggio](#) – 2024-2025 - concluso
- **QUantum ANalysis and Technology for Image Classification (QUANTIC)** – PNRR – responsabile dell’unità locale Università “Luigi Vanvitelli”: [Luigi Coraggio](#) – 2024 – concluso
- **The strongly correlated nuclear system (NUCSYS)** – Istituto Nazionale di Fisica Nucleare (INFN) - responsabile dell’unità locale Università “Luigi Vanvitelli”: [Luigi Coraggio](#) – 2024 – in corso

Principali Pubblicazioni Recenti:

(Elencare le pubblicazioni più rappresentative prodotte dal gruppo negli ultimi 5 anni)

1. S. Lyu, G. De Gregorio, T. Fukui, N. Itaco, L. Coraggio, *Realistic shell model for ordinary muon capture in sd-shell nuclei*, Phys. Rev. C 112 (2025) 054314, DOI: <https://doi.org/10.1103/jlk7-ldpf>.
2. G. Nunziata, S. Crisci, G. De Gregorio, R. Schiattarella, G. Acampora, L. Coraggio, N. Itaco, *Quantum fuzzy logic for edge detection: A demonstration on NISQ hardware*, Applied Soft Computing Journal 185 113866, (2025), DOI: <https://doi.org/10.1016/j.asoc.2025.113866>.
3. R. Li, D. Verney, C. Delafosse, G. De Gregorio, F. Didierjean, R. Mancino, I. Matea, L. Coraggio, L. A. Ayoubi, N. Itaco, H. Al Falou, G. Benzoni, F. Le Blanc, M. N. Harakeh, V. Bozkurt, M. Ciemata, I. Deloncle, M. Fallot, C. Gaulard, A. Gottardo, V. Guadilla, J. Guillot, K. Hadynska-Klek, F. Ibrahim, N. Jovancevic, A. Kankainen, Yu. G. Sobolev, I. Stefan, M. Lebois, T. Martínez, S. Stukalov, P. Napiorkowski, B. Roussiere, D. Thisse, and G. Tocabens, *Simultaneous impacts of nuclear shell structure and collectivity on β decay: Evidence from $^{80}\text{Ga}_{49}$* , Phys. Rev. C 111 (2025) 034303, DOI: <https://doi.org/10.1103/PhysRevC.111.034303>
4. A. Massa, G. Nunziata, F. Polverino, L. Campanile, M. Castaldo, L. Coraggio, S. Crisci, G. De Gregorio, W. Idrissi Ibsalikh, N. Itaco, E. Landolfi, S. Marrone, G. Toraldo, A. Troiano, *A Quantum Machine Learning Algorithm for Hazelnut Variety Recognition*, Proceedings of the 2025 IEEE International Conference on Quantum Artificial Intelligence (QAI), 2025, DOI: <https://doi.org/10.1109/QAI63978.2025.00018>
5. G. De Gregorio, R. Mancino, L. Coraggio, and N. Itaco, *Forbidden β decays within the realistic shell model*, Phys. Rev. C 110 (2024) 014324. DOI: <https://doi.org/10.1103/PhysRevC.110.014324>
6. L. Coraggio, N. Itaco, G. De Gregorio, A. Gargano, Z. H. Cheng, Y. Z. Ma, F. R. Xu, and M. Viviani, *The renormalization of the shell-model Gamow-Teller operator starting from effective field theory for nuclear systems*, Phys. Rev. C 109 (2024) 014301, DOI: <https://doi.org/10.1103/PhysRevC.109.014301>
7. L. Coraggio, G. De Gregorio, T. Fukui, A. Gargano, Y. Z. Ma, Z. H. Cheng, and F. R. Xu, *The role of three-nucleon potentials within the shell model: Past and present*, Prog. Part. Nucl. Phys. 134 (2024) 104079, DOI: <https://doi.org/10.1016/j.pnnp.2023.104079>
8. L. Coraggio, N. Itaco, G. De Gregorio, A. Gargano, R. Mancino, and F. Nowacki, *Shell-model calculation of ^{100}Mo double- β decay*, Phys. Rev. C 105 (2022) 034312, DOI: <https://doi.org/10.1103/PhysRevC.105.034312>

9. L. Coraggio, G. De Gregorio, A. Gargano, N. Itaco, T. Fukui, Y. Z. Ma, and F. R. Xu, *Shell-model study of titanium isotopic chain with chiral two- and three-body forces*, Phys. Rev. C 104 (2021) 054304, DOI: <https://doi.org/10.1103/PhysRevC.104.054304>
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