



RES-NOVA

Archaeological Lead based
cryogenic detector

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Astro-particles: low energy interactions

- What are low energy interactions?
- Why are they difficult to detect?
- Why is the choice of detector crucial?

Neutrinos



Dark Matter



→ among the most abundant particles in nature

→ cosmic messengers

RES-NOVA experiment - 1

The RES-NOVA experiment aims to detect astrophysical neutrinos, primarily from supernovae, using cryogenic detectors based on archaeological lead.

→ new experimental approach with cm-scale neutrino detector



RES-NOVA CRYOGENIC DETECTORS



4 cm

TRADITIONAL NEUTRINO DETECTOR

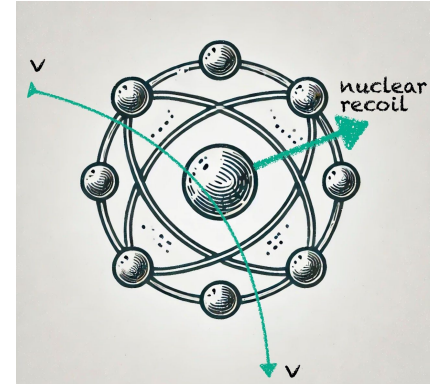


20 m

RES-NOVA is designed for operating in the underground Laboratory of Gran Sasso → the natural shielding reduces background interference from cosmic rays

RES-NOVA experiment - 2

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS): a process where low-energy neutrinos scatter off entire atomic nuclei coherently. This scattering occurs when the neutrino wavelength is comparable to or larger than the nucleus, allowing all nucleons to participate coherently in the interaction.



Archeological lead detector:

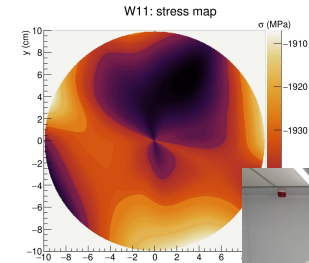
in RES-NOVA the archaeological Pb is not only used as shielding but also in the production of PbWO_4 crystals, which further improves the overall sensitivity of the detector to faint astrophysical signals.

- high statistics (largest cross-section)
- ultra-low-background

Proposed thesis topics - 1

1. Design optimization of Transition-Edge Sensors (TES)

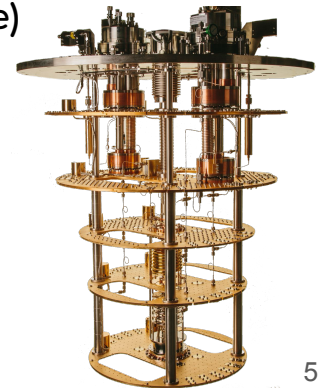
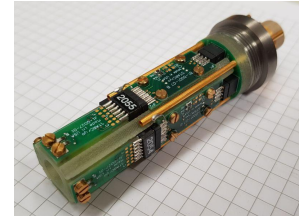
- Nanofabrication and characterization of sensors
- Analysis of the sensor response as a function of TES parameters
- Stress measurements
- Cleanroom work at Politecnico di Milano



Thesis work starting soon!

2. Characterization of SQUIDs (Superconducting Quantum Interference Device)

- Noise measurements
- Study of TES transition curves
- Slew-rate measurements and I-V curve acquisition
- Laboratory work in the U9 building (cryostat)

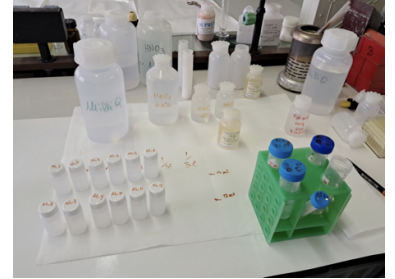


Thesis work starting soon!

Proposed thesis topics - 2

3. Study of radioactivity in ancient Roman metallic lead samples using scintillation techniques

- Sample preparation
- Operation of the Quantulus low-background scintillation counter
- Work in the radioactivity laboratory on floor -2 of the U2 building



Thesis work starting in september

4. Study of a detector and analysis of the light-heat readout

- Performance characterization of the crystal
- Data analysis performed with an existing analysis framework
- Work carried out at Milano-Bicocca and at the LNGS laboratories



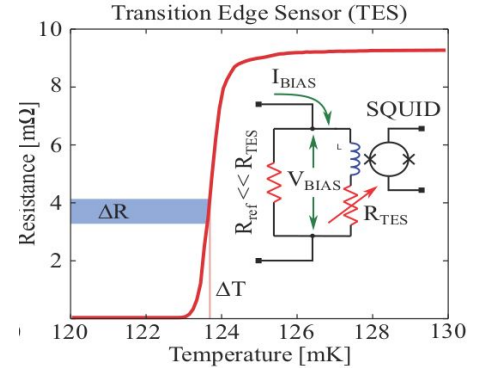
Thesis work starting soon!

Proposed thesis topics - 3

5. Development of a stabilization system for RES-NOVA detector

- Study of TES transition characteristics
- Implementation of the detector stabilization software
- Electronics already available

Thesis work starting soon!



6. ICP-MS measurements

- Material screening
- Work carried out at Milano-Bicocca and at the LNGS laboratories

Thesis work starting soon!

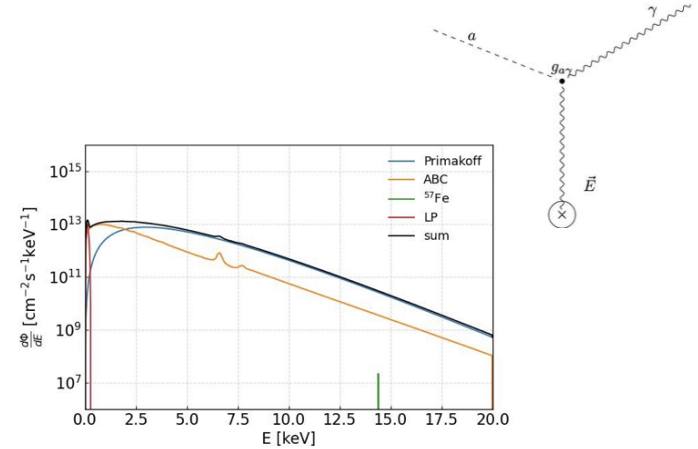


Proposed thesis topics - 4

7. RES-NOVA sensitivity to supernova physics

- Analysis of core-collapse supernova modeling
- Analysis of the RES-NOVA detector response to supernova explosions
- Investigation of axion detection

Thesis work starting soon!



8. Characterization and 3D printing of lead

- Investigation of the critical current density
- Study of magnetic impermeability

Thesis work starting soon!

More information

Contact us!

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May 2026 @ UNIMIB/F3nice

2nd RES-NOVA General Meeting

We are having our 2nd General Meeting at the Gran Sasso Labs. A great opportunity to meet (almost) all colleagues in person and discuss the huge amount of work that lies ahead of us! Go RES-NOVA 🚀

(Collaboration picture on the left)

Visit our website:

<https://res-nova.unimib.it/>

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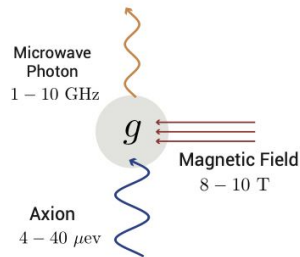
QUANTUM SENSING

The Axion: A Dark Matter Candidate

The **axion** is a hypothetical particle proposed to solve the strong CP problem in quantum chromodynamics.

Key Characteristics:

- Potential major component of **dark matter**.
- Interacts very weakly with ordinary matter and light.
- Comes from a well-defined theoretical framework.

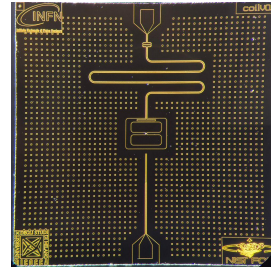


Quantum Sensing for Detection

Detecting dark-matter axions requires ultra-weak signal detection beyond classical limits.

How Quantum Sensing helps:

- **Qubit-based sensors:** Enable sensitivity beyond the Standard Quantum Limit.
- **QND Photon Counting:** Enables repeated, non-destructive photon measurements, suppressing detector noise and improve sensitivity to weak signals.

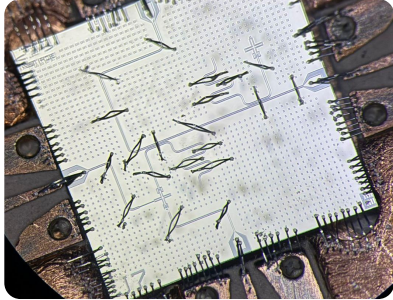


WHAT DO WE USE?

Qubits

Designed in Quantum Metal, simulated with Ansys HFSS and Q3D, and characterized in our lab.

The present chip hosts two Xmon qubits with drive and flux lines, and multiplexed readout.

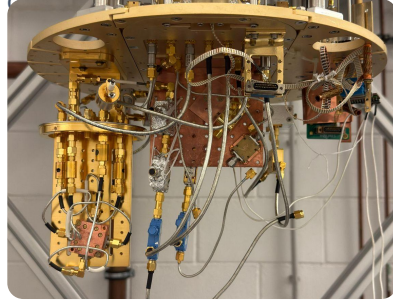


Dilution Refrigerators

Elsa and **Anna** help us to cool down our devices at 10 mK!

At these temperatures the noise is *very low* and our devices become *superconducting!*

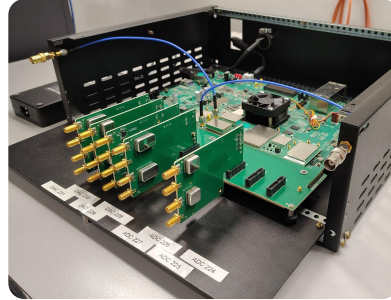
This makes our lab one of the coldest places in the universe!



RFSoc Electronics

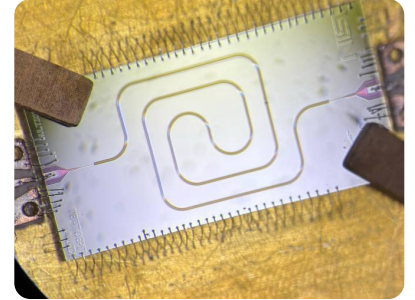
To characterize our devices and perform experiments, we develop custom firmware and software for state-of-the-art FPGA-based electronics.

This gives us full control over the experimental workflow.



KITWPAs

A kinetic inductance travelling-wave parametric amplifier that boosts our weak signals by mixing them with a pump tone, while adding only the minimum noise allowed by quantum mechanics.



BSC THESIS PROPOSALS

1. Benchmarking of a RFSoc-based control system for quantum sensing

Modern control and data acquisition systems used in particle physics experiments and quantum technologies increasingly rely on tight integration between digitization, real-time processing, and high-stability RF control. RFSoc platforms provide a highly integrated alternative to discrete architectures.

Thesis Goal:

Perform systematic benchmarking of feedback loop stability, phase noise, latency, and signal fidelity in superconducting qubit control. Includes defining metrics and implementing experimental setups.

2. Reaching the Quantum Limit in Axion Detection: Sensitivity Bounds via QFI

Detecting dark-matter axions requires ultra-weak signal detection. Superconducting transmon qubits as QND photon counters enable sensitivity beyond the Standard Quantum Limit, though limited by thermal background and decoherence.

Thesis Goal:

Carry out a systematic sensitivity study of a qubit-based axion detector using Quantum Fisher Information (QFI) to establish fundamental theoretical bounds on axion-photon coupling estimation.

MSC THESIS PROPOSALS

1. Design, Simulation and Characterization of a Superconducting Qubit Sensor for Axion Dark Matter Detection

Design and simulation of a sensor for axion Dark Matter detection using transmon qubits and QND photon counting.

Key Activities:

- Layout with Quantum Metal
- FEM simulations (HFSS, Q3D)
- Hamiltonian parameter extraction
- Experimental characterization

2. FPGA implementation of advanced readout techniques for quantum sensing

Development of firmware for real-time extraction of interferometric error signals (PDH locking) for quantum sensing.

Focus Areas:

- Digital architecture design
- RFSoc implementations
- Noise & latency optimization
- Laboratory validation

3. Development of Higher-Dimensional Quantum Architectures for Computing, Simulation and Sensing

Exploiting qudit systems (multi-level transmons) for advanced computing, simulation, and sensing.

Research Goals:

- Qibo-based qudit simulator
- Multi-level quantum gates
- Many-body dynamics simulation
- Dark matter sensing protocols

More information is available [here](#).

WHY DO YOUR THESIS WITH US?



STATE-OF-THE-ART LABORATORIES

Work in laboratories equipped with state-of-the-art dilution refrigerators (meet **Elsa** and **Anna**!) and cutting-edge electronics.



INTERNATIONAL EXPERTISE

Learn from our PhD students who have gained international experience through six-month research periods at leading **universities**, **companies**, and **institutions**, including Chalmers University of Technology, TU Delft, the University of Waterloo, IQM, Intermodulation Products, and NIST.



EXPERIMENTAL TRAINING

Learn the full workflow of device characterization, from chip preparation and wire bonding to sample installation, experimental setup, and complete device characterization.



ANALYTICAL SKILLS

Develop valuable skills in high-level programming (Python, VHDL), data analysis, automation, and problem-solving.

USEFUL INFORMATION

If you are interested in a thesis project in **quantum technologies**, or if you have any questions, please get in touch with the group!

MEMBERS

GROUP LEADER

[Angelo Nucciotti](#)

PROJECT LEADERS

[Marco Faverzani](#), [Elena Ferri](#), [Andrea Giachero](#)

RESEARCHER

Matteo Borghesi

PHD STUDENTS

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Sara Gamba, Marco Gobbo

ALUMNI

Danilo Labranca ([QuantWare](#)), Roberto Moretti ([IQM](#))

ACADEMIC COLLABORATION

We maintain strong academic ties with prestigious international institutions for research exchange and collaborative projects, including **NIST**, **MIT**, **CU Boulder**, **University of Waterloo**, **TU Delft (QuTech)**, **EPFL**, **SKKU**, **Chalmers University of Technology**, **Lancaster University** and more!

INDUSTRY COLLABORATION

We collaborate with leading companies in the quantum ecosystem, including **Plankian**, **QuantWare**, **IQM**, **Intermodulation Products**, **Silent Waves** and more!



Thank you for the attention!