SQMS Italy –Welcome Remarks and introduction

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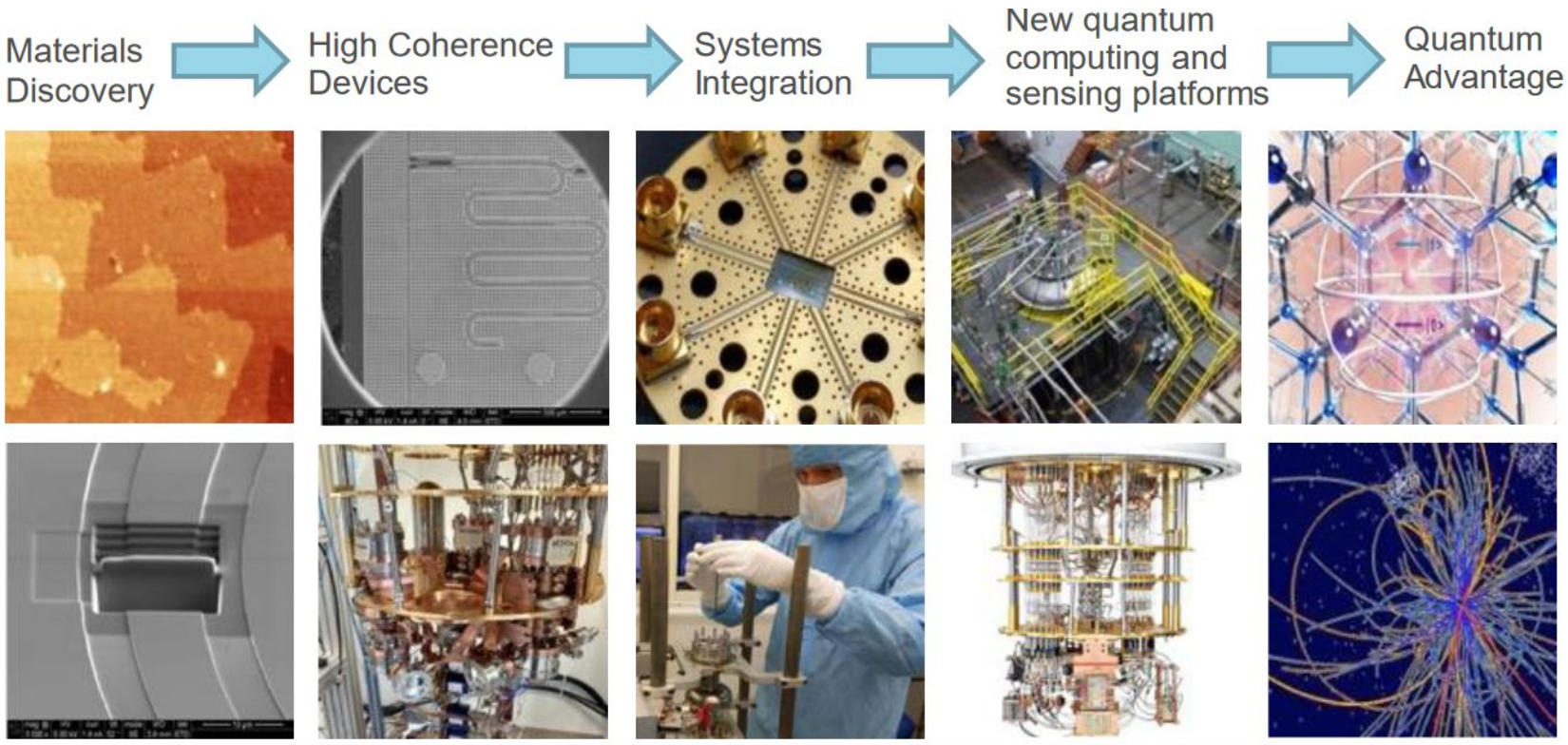
INFN – Trieste

SQMS-INFN Workshop on Quantum Technologies for Fundamental Physics, Erice, 1 – 7 September 2023

The DOE-SQMS Center

SQMS Roadmap: from material discovery to quantum advantage



INFN is a contributing partner

The timeline

- March 2020: SQMS project presented to DOE
- September 2020: DOE “informal” approval
- October 2020: Official start of SQMS
- February 2021: MoU between FNAL and INFN
- April 2021: SQMS officially recognized by INFN
- …… (a lot of exciting work!)
- September 2025: formal closing of the project

In the meantime, during 2021/2022…

- INFN developed its strategy for QC/QT within the PNRR funding opportunities, leading to:
  - Spoke dedicated to Quantum Computing within the National Centre for High Performance Computing (PNRR funding)
    - INFN leader of WP1 (Software): Development and application of high-level quantum software for algorithms solving general purpose problems, scientific and industrial applications
    - INFN actively involved in WP3 (Firmware and hardware platforms): Development and support of the quantum computer hardware chain.
  - INFN involved in the National Quantum Science and Technology Institute (NQSTI) (Extended Partnerships, PNRR funding)
    - Focus on low-TRL R&D in the field of QST, for innovative applications in sensing, safe communication, processing of quantum information; development of concepts, new materials and devices (photonic, solid state and cold).
    - INFN involved in spokes 3 (cold atoms), 4 (photonics), 6 (integration), 8 (technology transfer) and 9 (outreach)

INFN within SQMS

- A Theory + Technology challenge, driven by HEP technology
- INFN units involved: LNF, LNGS, LNL, GGI, Padua, Florence, Ferrara, Rome, Trieste, Milan-Bicocca (> 30 people)
- INFN contributes to three Focus Areas as, well as to development of the QIS ecosystem (Workforce Development):
  - In **Focus Area 1 - Materials for 2D and 3D quantum systems,** INFN contributes in:
    - Characterization of superconducting components (e.g., cavities and qubits), including the assessment of the impact of environmental perturbation, taking advantage of the very low radioactivity environment of the LNGS - Gran Sasso Laboratory.
    - Development of appropriate mitigation techniques against environmental perturbation.
    - Theoretical support.
  - In **Focus Area 2 – Quantum Device Integration, Prototypes and QPUs,** INFN contributes in:
    - mK cryogenic support.
    - Establishment of a state-of-the-art cryogenic, low-noise facility for the characterization and test of quantum devices.
    - Theoretical support.
  - In **Focus Area 3 – Quantum Physics & Sensing**, INFN contributes in:
    - Improvements to the design and sensitivity of haloscope detectors at high frequency (~ 10 GHz), including the continued development of high-Q cavities in high B fields.
    - Demonstration of the use of these detectors for Dark Matter searches.
    - Theoretical support.

People and budget

Structure	Local coordinator
GGI	S. De Curtis
LNGS	C. Bucci
LNL	G. Ruoso
LNF	C. Gatti
Sezione di Firenze	L. Banchi
Sezione di Padova	C. Braggio
Sezione di Pavia	L. Maccone
Sezione di Roma 1	L. Cardani
Sezione di Trieste	V. Bonvicini
Sezione di Ferrara	P. Fabbri (Administrative support)

- SQMS: $ 16719000
- SQMS_FOE: € 287250

Milestones 2021 & 2022

- 2021
  - Commissioning of a characterization station at LNGS ☺
  - Radio-pure Cu shields ☺
  - mK testbed for Axion DM search ☺

- 2022
  - SQMS/GGI Summer School on Quantum Simulation of Field Theories ☺
  - Delivery to FNAL of a 4 GHz NbTi sputtered cavity ☺
  - Characterization of the performance of a qubit in the low-radioactivity environment of LNGS ☺

The SQMS-GGI summer school (July 2022)

- Topic: Quantum Simulation of Field Theories, 25 – 29 July 2022, Galileo Galilei Institute (Florence)
- 35 students in person + 35 on-line

Raffaele “Lele” Tripiccione, 1956 - 2021

- Remembering prof. Raffaele Tripiccione two years after his untimely passing
- Lele’s enthusiasm and vision was the driving force that started the INFN-SQMS collaboration (besides many other initiatives and contacts in the QC/QT field)

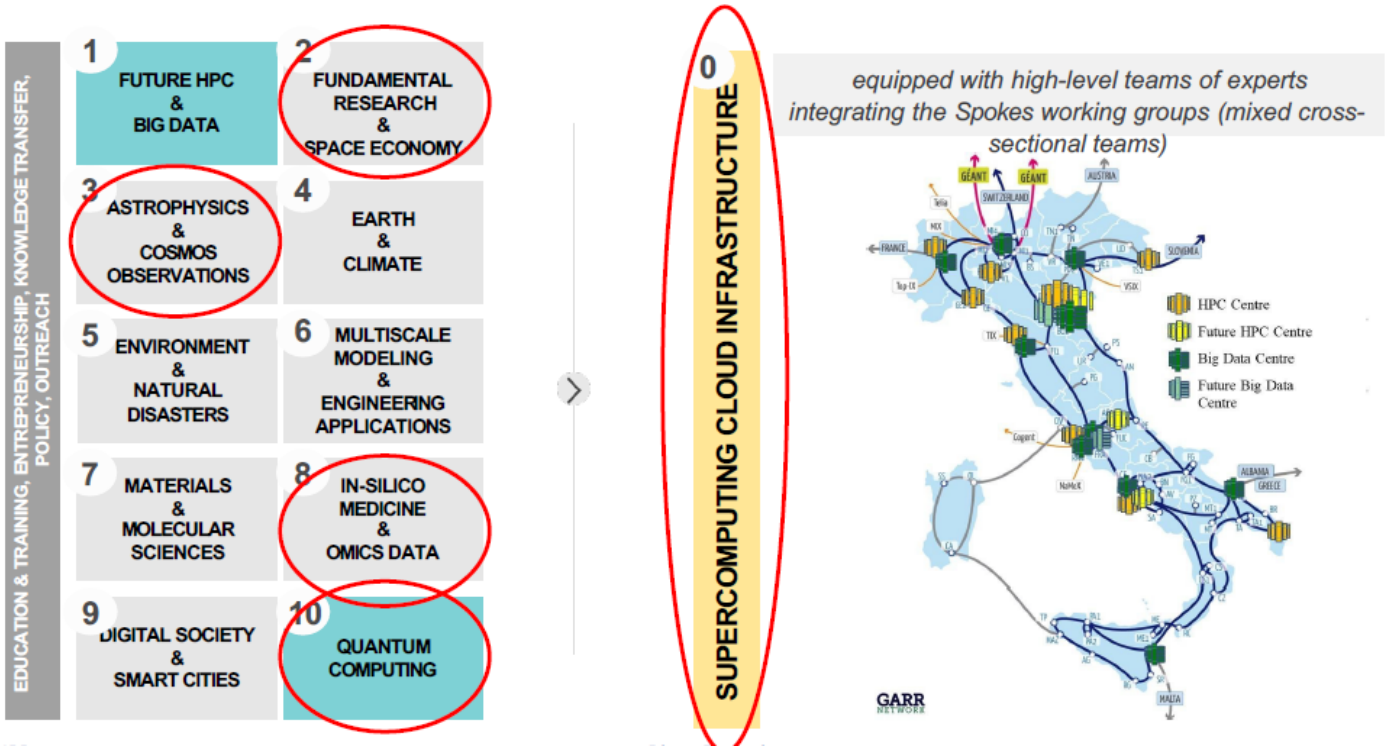
Spare slides

QIS/QT and INFN

- INFN and QIS - the long-term goal:
  - Adopt all technologies that can allow better research in fundamental physics (e.g., detect very low energy quantum states).
  - Use Quantum computers/simulators to support our research (from Lattice QCD, to event classification in LHC, to Life Science applications).
  - Contribute to QC/QT with HEP-derived knowledge, know-how, technology (theory, SC resonant cavities , mK cryogenics,…).
- How?
  - Team with other players, in Italy and elsewhere, sharing scientific interests and/or technology options.
  - Develop a sound know-how and an expert workforce.
- Main QIS/QT current activities (carried on in INFN-financed experiments, within PNRR-financed projects, and in International projects):
  - Theory/algorithms
  - Technology: SC platform, Photonic platform, Cryogenic detectors (TES, KIDs, JJ,…), QL-parametric amplifiers, qubits for QC and sensing
  - Science: measurement of ν mass, Axion (and light DM) search, QML and quantum algorithms for HEP
- Several important collaboration with U.S. Institutions already active (with further interesting perspectives)

PNRR-funded activities: Quantum Computing within the National Center for HPC

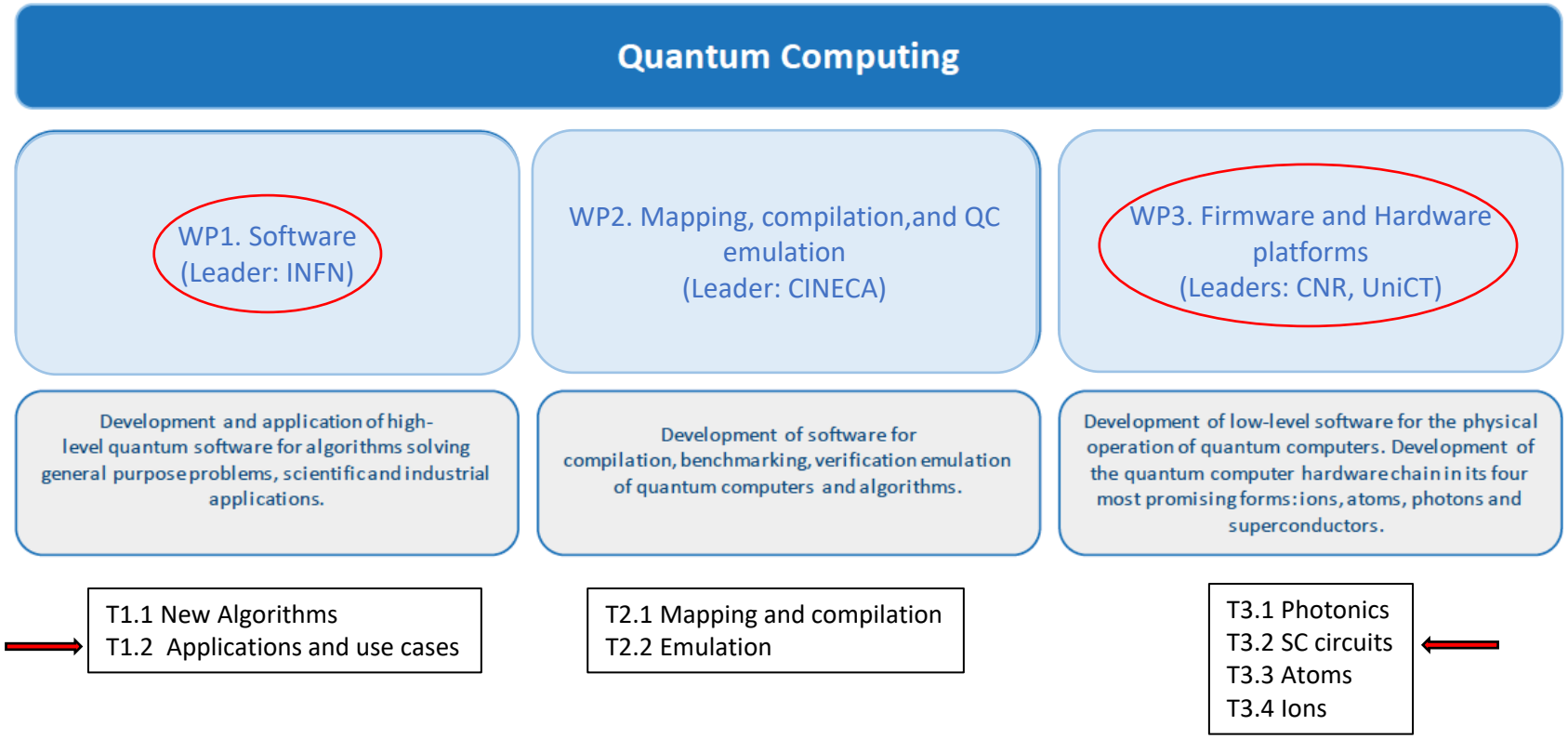
- The Center (PNRR funding) includes *ten thematic spokes* and *one infrastructure spoke*



What we want to do

- Our view: team with a large/high level community, learn & contribute
- Our contributions/expectations:
  - Theory at the foundational/metrological levels
  - Theory and algorithms for quantum applications
  - Measure and mitigate the negative impact of radioactive background
  - Contribute/improve our expertise in superconducting cavities
  - Couple transmons and (B-friendly) cavities
  - Find the axion... ☺
  - Make LNGS (and other places?) a test/characterization facility for quantum devices
  - Ph.D. schools/workshops/conferences at GGI (and elsewhere)
  - Help young people enter this field

Quantum Computing (Spoke 10) within the National Centre for High Performance Computing



INFN activities in WP1 (Software)

- Applied quantum algorithms: exploit the potential of Quantum Computing to change the paradigm of classification and reconstruction algorithms used in fundamental physics research:
  - Tackle classification problems within the framework of QML
  - Study correlations amongst the features of a dataset, by measuring the entanglement correlations between qubits, and therefore extracting information on the underlying physics
  - quantum algorithms can be employed to efficiently reconstruct physics objects, such as charged particle tracks, specifically to reduce combinatorial background during the initial seeding stage

PNRR-funded activities: National Quantum Science and Technology Institute (NQSTI)

The National Quantum Science and Technology Institute is a consortium that will:

1. Team up Italian entities carrying out competitive and innovative research in QST.
2. Stimulate future industrial innovation in this field.
3. Provide a forum in which novel ideas and opportunities are transferred to companies.
4. Favor successful Italian participation to European and international program.

Research TRLs
1-4

20 Institutions

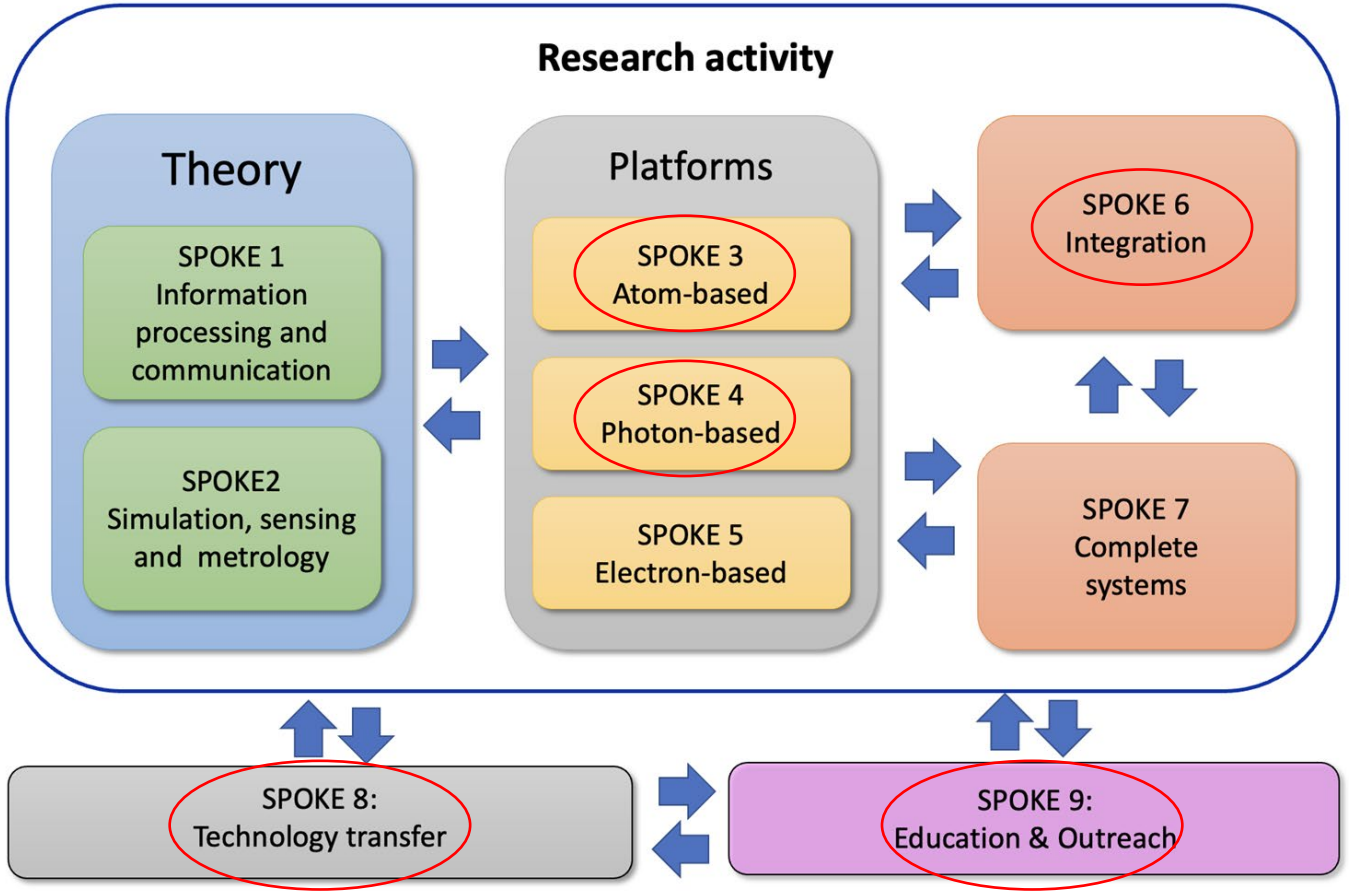
Researchers
322

New RTD⁺
94+10

MUR funding
116 M€

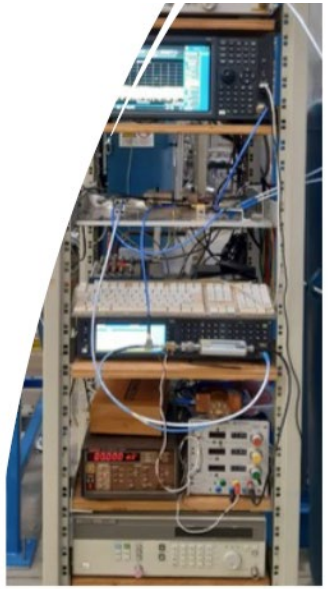
Open calls
23 M€

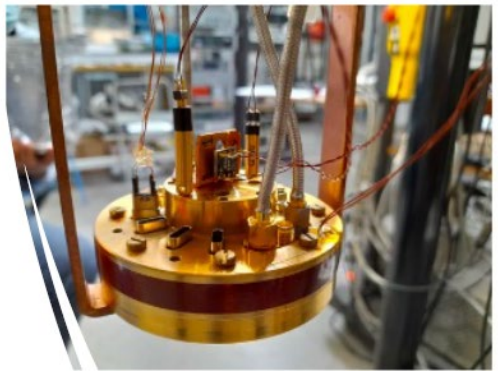
PNRR-funded activities: National Quantum Science and Technology Institute (NQSTI)



INFN activities in WP3 (Hardware)

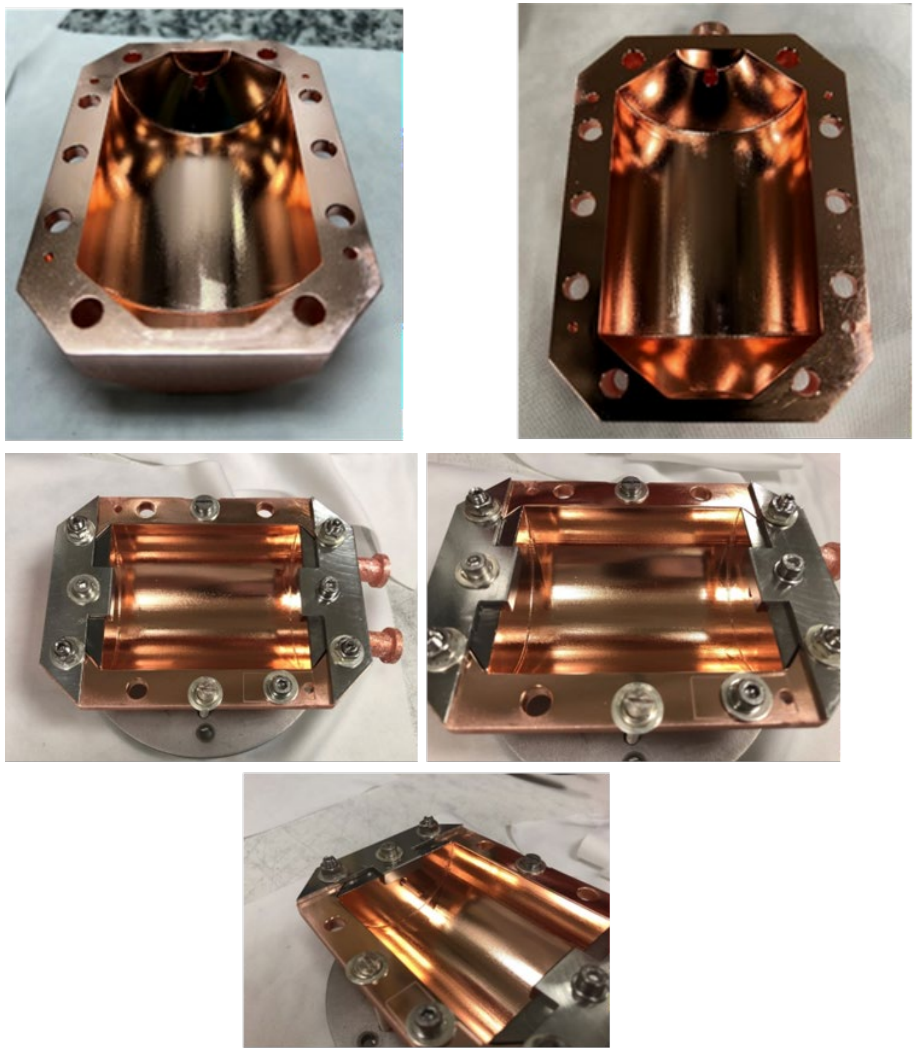
- Superconducting qubits
  - Qubit circuit design
  - Qubit control
  - Test and Development of Quantum Amplifiers for fast qubit readout
  - Test and Measurements
- 5 INFN laboratories instrumented with dilution refrigerators and RF electronics





SQMS: 3.9 GHz NbTi SC cavity for light DM (axion) search

- Designed and realized at LNF and LNL
- Electropolished and sputtered with NbTi
- Delivered to FNAL on Dec. 13, 2022



SQMS: 9 GHz Nb_3Sn SC cavity for light DM (axion) search

- Designed and realized at FNAL
- To be shipped to LNF
- Will be tested at LNF in a dilution refrigerator with 6 T (later 9 T), and readout with the TWPAs designed by DARTWARS

Assessing the impact of environmental radioactivity

Regular Article - Experimental Physics | Open Access | Published: 31 January 2023

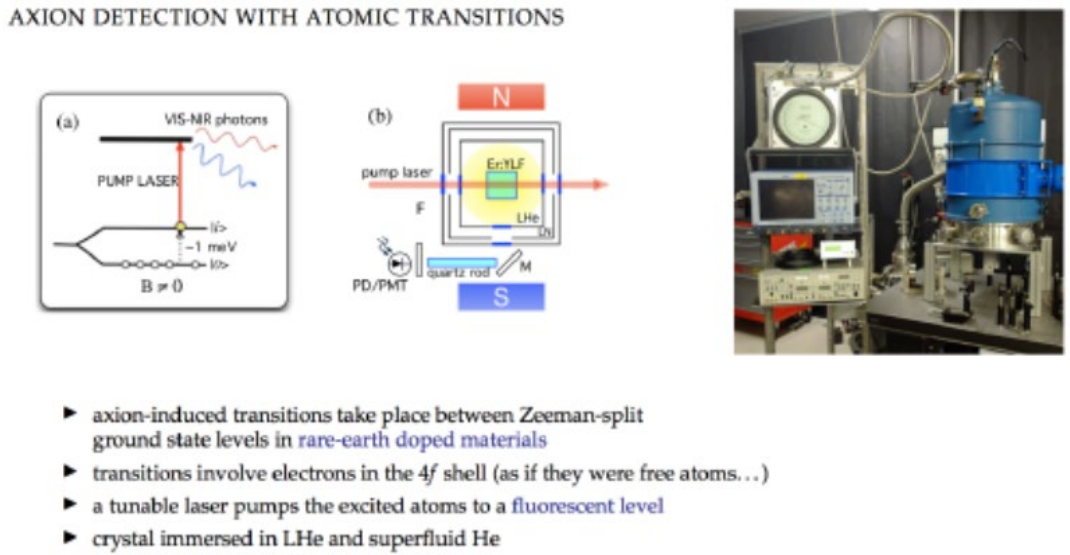
Disentangling the sources of ionizing radiation in superconducting qubits

L. Cardani, I. Colantoni, A. Cruciani, F. De Dominicis, G. D'Imperio, M. Laubenstein, A. Mariani ✉, L. Pagnanini, S. Pirro, C. Tomei, N. Casali, F. Ferroni, D. Frolov, L. Gironi, A. Grassellino, M. Junker, C. Kopas, E. Lachman, C. R. H. McRae, J. Mutus, M. Nastasi, D. P. Pappas, R. Pilipenko, M. Sisti, V. Pettinacci, A. Romanenko, D. Van Zanten, M. Vignati, J. D. Withrow & N. Z. Zhelev — Show fewer authors

The European Physical Journal C **83**, Article number: 94 (2023) | Cite this article

Examples of activities/interests within NQSTI/S3

- Long Coherence Spin Time (in excess of ms) for e and p EDM measurements in Molecules
- Macro-Coherent sensors for Dark Matter (neutrino ?) detection



- Atomic Ion Source with High Charge State for Atomic Clocks