



UNIVERSITÀ DEGLI STUDI DI NAPOLI
FEDERICO II

iteePhD
information technology
electrical engineering



Davide Cuneo

Advanced Instrumentation for AC Losses Measurement and Quench Detection in HTS Accelerator Magnets

Tutor: Prof. Pasquale Arpaia

Cycle: XXXVIII

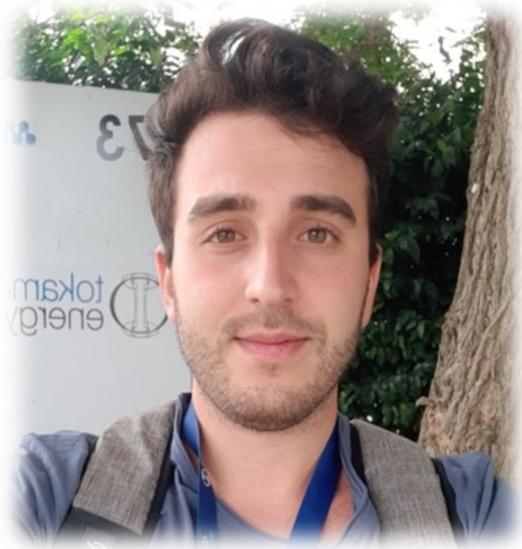
co-Tutor: Prof. Pedro Ramos

Year: Third

Candidate's information

Davide Cuneo

email: davide.cuneo@unina.it



- **Ph.D.** in Information Technology and Electrical Engineering (ITEE), University of Naples Federico II (2023 - on going)
- **MSc degree** in Mechanical Engineering, University of Tuscia, (2020-2022)
- **Research project:** PNRR IRIS (Innovative Research Infrastructure on applied Superconductivity) project.
- **Period abroad:** Lawrence Berkeley National Laboratory (LBNL), Berkeley, California



2022

2023

2024

2025



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FEDERICO II



Summary of study activities

Training on data analysis and measurement methods

- Statistical Data Analysis for Science and Engineering Research
- Data Uncertainty
- Ph.D. School Italo Gorini in applied metrology
- Instrumentation and Diagnostic for Superconducting Magnets (IDSM-2 workshop): Superconducting Magnets Test stands, Magnet Protections and Diagnostics
- CERN Accelerator school: “Normal- and Superconducting Magnets”

Numerical analysis and particle accelerator schools

- Modelli numerici per I campi elettromagnetici
- Introduction of computational fluid dynamics
- U.S. Particle Accelerator School: Magnetic Systems for Accelerators, Detectors and Insertion Devices
- U.S. Particle Accelerator school: i) Superconducting Accelerator Magnets & ii) Optimization and Machine Learning for accelerators

Summary of study activities

Seminars

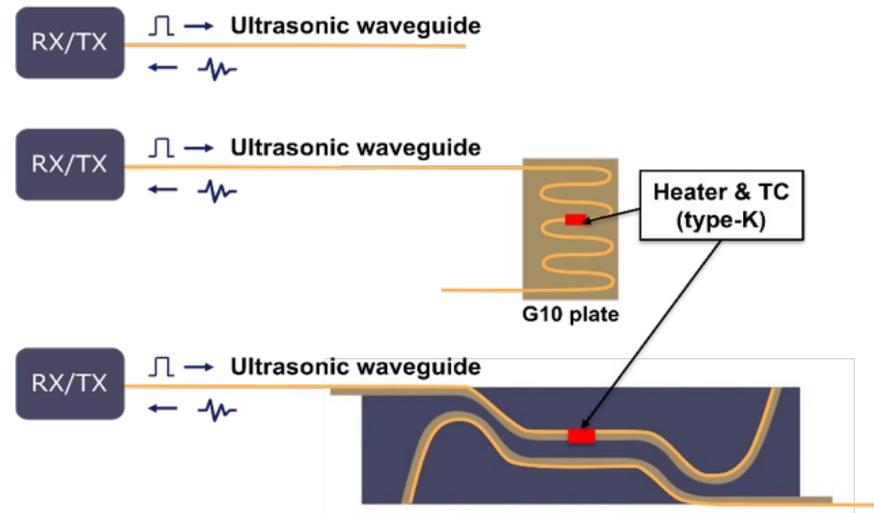
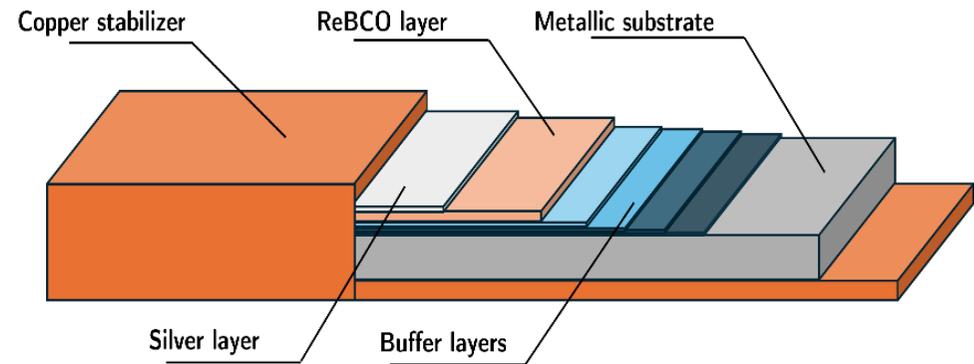
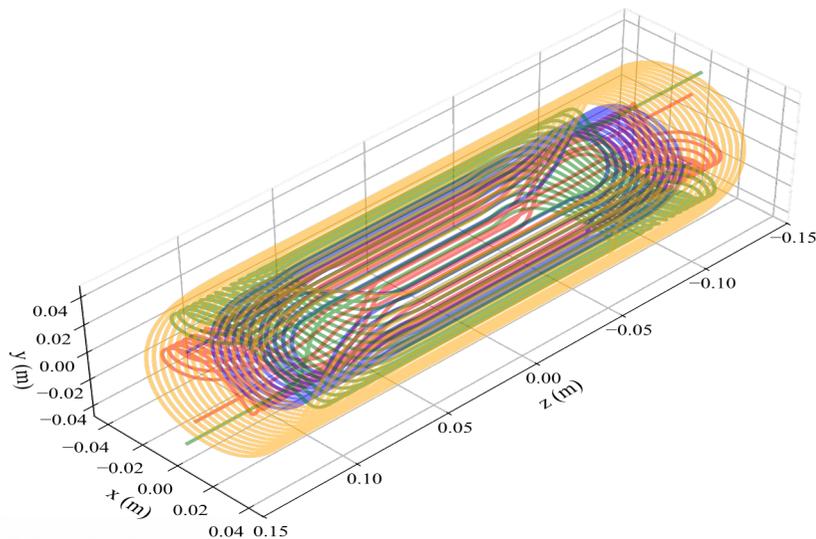
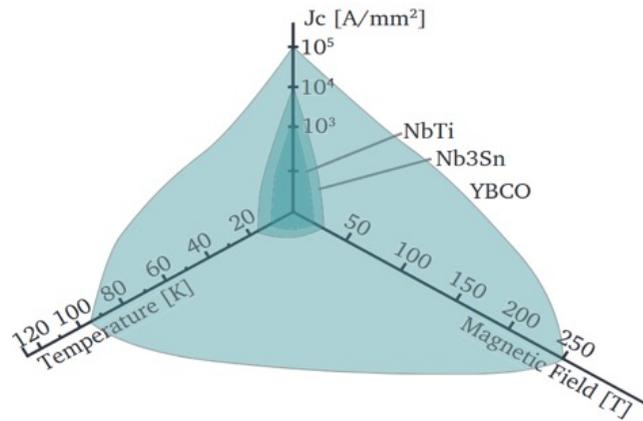
- **Update on Superconducting Magnets & Devices Development at CERN**, Dr. Arnaud Devred
- **Fast normal zone propagation velocities in stacks and CORC cables made with CFD REBCO-tapes**, Prof. Frédéric Sirois
- **Exploiting novel liquid sheet targets for the generation of bright MeV proton beams**, Dr. Charlotte Palmer
- **The challenge of designing HTS magnets: could that trigger synergies among the fusion and the particle physics communities?**, Prof. Laura Savoldi
- **AC loss issues in all-superconducting rotating machines for aircraft applications**, Zhenan Jiang
- **Next-gen magnet insulation: NI and MIT technologies at PSI campus**, Mattia Ortino
- **Development and operation of high field cryogen-free superconducting magnet at HFSLM**, Dr. Satoshi Awaji
- **Status of Superconducting Magnet Projects and R&D at KEK**, Prof. Toru Ogitsu
- Other seminars listed in the TRAR...

Conferences and Workshops

- 2nd Instrumentation and diagnostic for superconducting magnets (2nd IDSM), Paestum (NA).
- Applied Superconductivity conference 2024 (ASC2024), Salt Lake City, Utah, 2024, USA
- Magnet Technology 29 (MT29), Boston, Massachusetts, 2025, USA
- Forum Nazionale delle misure 2025, Napoli, Italia

Research area(s)

Advanced Instrumentation for AC losses measurement and Quench detection for HTS magnets



Research results

- **AC losses measuring instrument for superconducting magnets:** conceptual and physical design of the measurement instrument for ramped magnets, supported by a Monte Carlo analysis for uncertainty evaluation.
- **Development of the first HTS uni-layer magnet prototype:** design, fabrication, and testing of the CORC-based prototype coil, demonstrating the feasibility of this innovative design for ReBCO-based small aperture magnets
- **Ultrasonic waveguide sensor for quench detection and localization:** development and experimental validation of a distributed temperature monitoring sensor for HTS magnets for quench detection.
- **Quench analysis of the Corrector Quadrupole Magnets via Machine Learning:** implementation and benchmarking of SVC for quench detection and localization on the corrector quadrupole magnets for the Hi-Lumi upgrade of LHC at CERN

Research products (1/2)

[P1]	Arpaia, D. Cuneo, A. Esposito, A. Gilardi, P. M. Ramos, <i>An Overview on Quench Detection Techniques for High-Temperature Superconducting Cables and Magnets [Roadmap for Measurement and Applications],</i> IEEE Instrumentation & Measurement Magazine, vol. 27 (9), pp. 29–37, Dec. 2024, DOI: 10.1109/MIM.2024.10772016.
[P2]	Arpaia, D. Cuneo, E. De Matteis, A. Esposito, P. Ramos, <i>Design and Uncertainty Analysis of an AC Loss Measuring Instrument for Superconducting Magnets,</i> Instruments, vol. 9 (8), 2025, DOI: 10.3390/instruments9020008.
[P3]	Cuneo, J. L. Rudeiros Fernández, P. Ferracin, M. Marchevsky, A. Esposito, P. Arpaia, <i>Design and implementation of an acoustic waveguide quench detection and localization sensor for the HTS Unilayer magnet prototype,</i> IEEE Transactions on Applied Superconductivity, 2025, DOI: 10.1109/TASC.2025.3627164.
[P4]	Trigilio, I. Balossino, L. Capuano, D. Cuneo, M. Del Franco, L. Petrucciani, L. Sabbatini, A. Selce, <i>Measurements of hysteretic effects and eddy currents on a FeCo magnet for the design of a novel ion gantry,</i> IPAC'24 (International Particle Accelerator Conference), Nashville, TN, USA, May 2024, pp. 1766–1769, DOI: 10.18429/JACoW-IPAC2024-TUPS47.

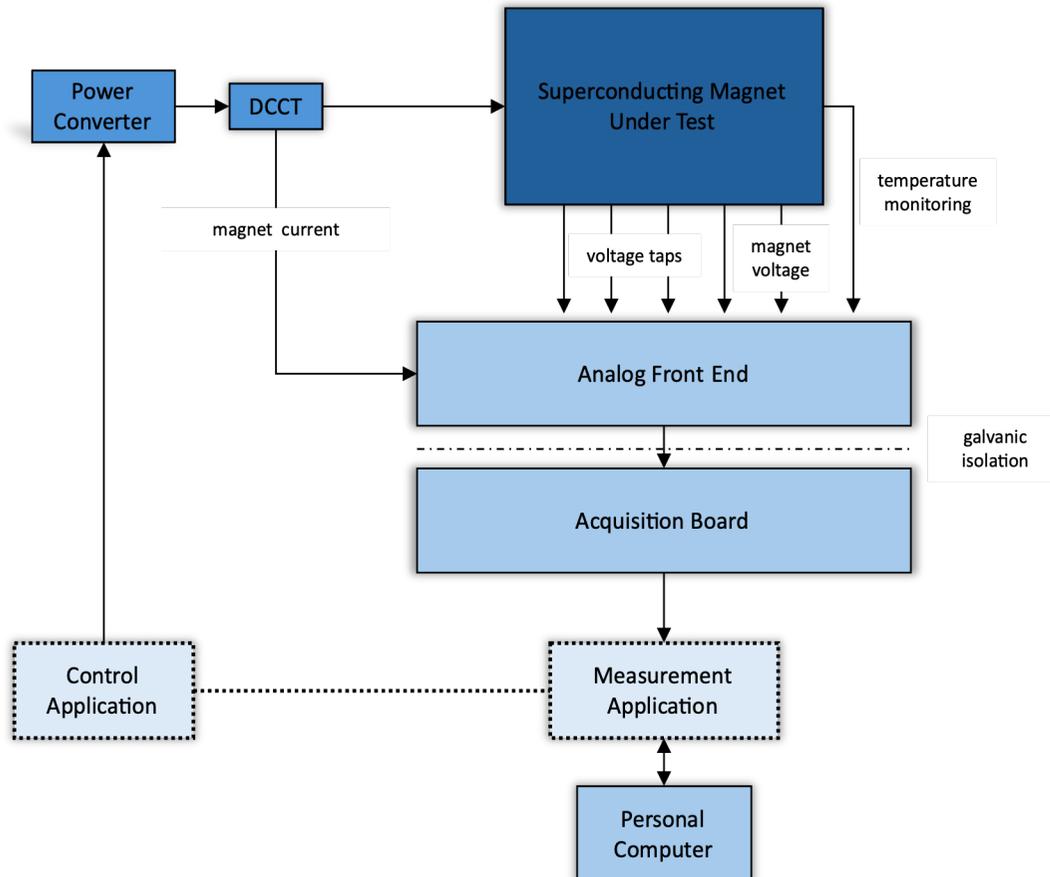
Research products (2/2)

[P1]	Vannozzi, G. Armenti, I. Balossino, L. Capuano, A. Casamatta, D. Cuneo, F. Iungo, S. Martelli, L. Petrucciani, L. Sabbatini, F. Sardone, et al., <i>Magnetic measurements for Halbach-type permanent quadrupoles using a single-stretched wire system</i> , IPAC'24 (International Particle Accelerator Conference), Nashville, TN, USA, May 2024, DOI: 10.18429/JACoW-IPAC2024-THPS54.
[P2]	Manzo, P. Arpaia, M. Balato, D. Cuneo, F. Mancino, S. Minucci, N. Moccaldi, C. Petrarca, <i>FEM-based Parametric Optimization of a Measurement Setup for Sensitivity Improvement in Insulin Absorption Assessment</i> , 2024 IEEE International Instrumentation and Measurement Technology Conference (I2MTC), Glasgow, Scotland, UK, May 2024, pp. 1–6, DOI: 10.1109/I2MTC60896.2024.10560806.

PhD thesis overview

- **Problem Statement:** HTS materials are essential for high-energy physics but suffer from **slow normal zone propagation** (making quenches difficult to detect with standard voltage monitoring techniques) and **dynamic heat loads** (AC losses).
- **Objective:** To develop and validate **advanced instrumentation** and methodologies for precise **AC loss evaluation** and reliable, non-invasive **quench detection** and localization for HTS particle accelerator magnets.
- **Methodology:** A multi-disciplinary approach relying on the **design and development of a dedicated measurement station** for AC losses (validated via Monte Carlo analysis), **hardware prototyping** of novel magnet configurations (Uni-layer) and sensors, and **data-driven analysis** (ML).

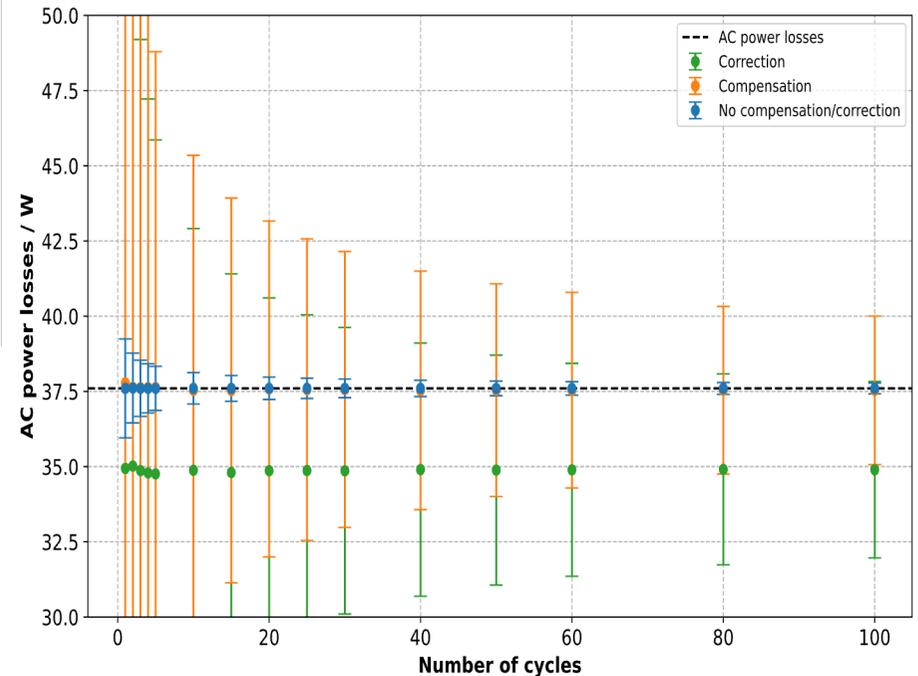
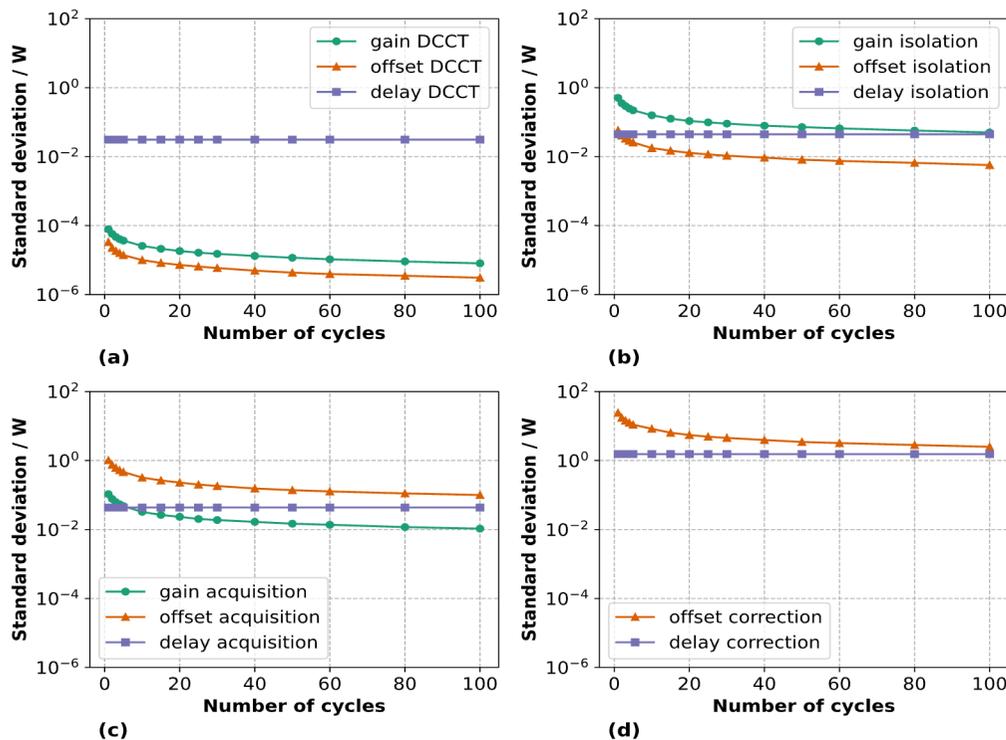
AC losses measuring instrument for SC magnets (1/2)



- **Instrument Design:** Development of an FPGA-based instrument (volt-ampere method), specifically tailored for the **1 W to 100 W** power range of accelerator magnets.
- **Uncertainty Evaluation:** Monte Carlo simulation to propagate uncertainties from individual components (sensors, DAQ) to the final power measurement

AC losses measuring instrument for SC magnets (2/2)

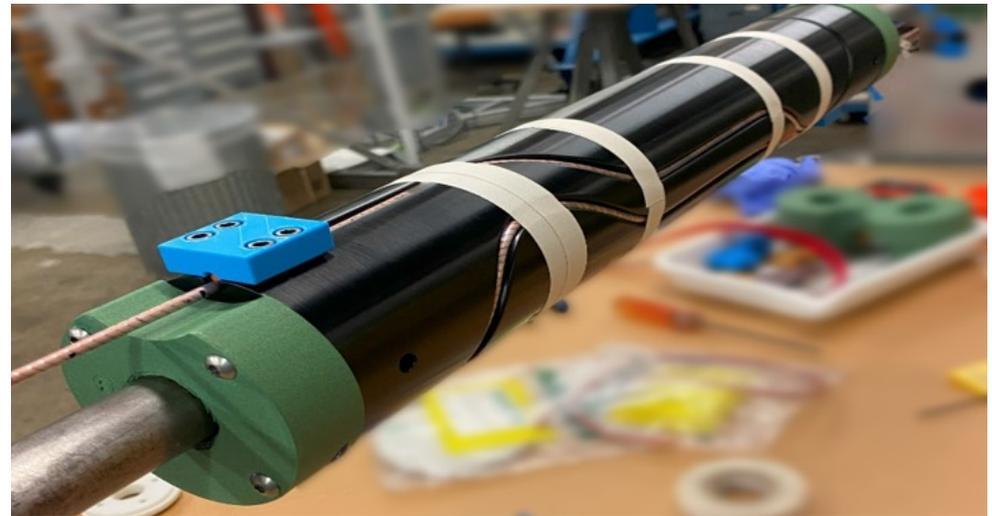
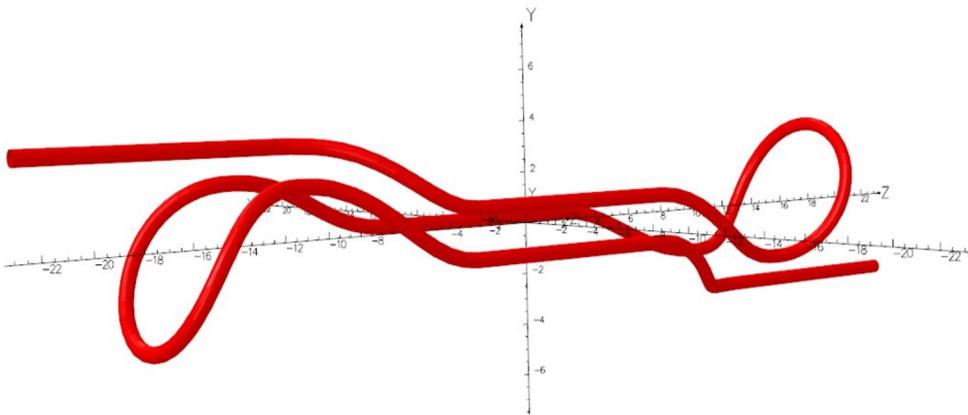
- **Measurement Strategies:** direct integration, numerical correction (software), and hardware compensation (derivative sensor).
- **Comparison of Methods:** *direct integration* minimizes uncertainty, achieving the target accuracy of **< 0.1 W**.



- **Sensitivity Analysis:** The analysis identified the **voltage offset** of the acquisition module as the dominant uncertainty source

Development of the first HTS uni-layer magnet prototype (1/2)

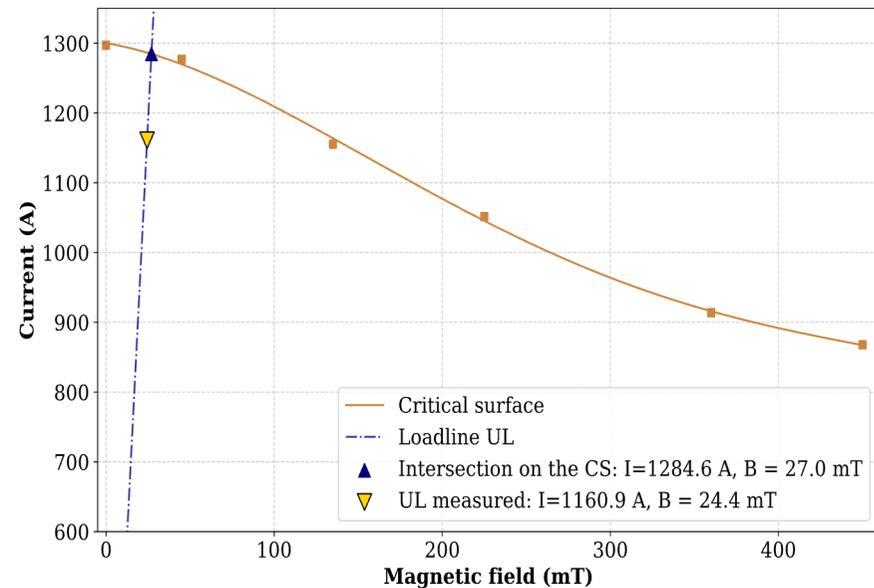
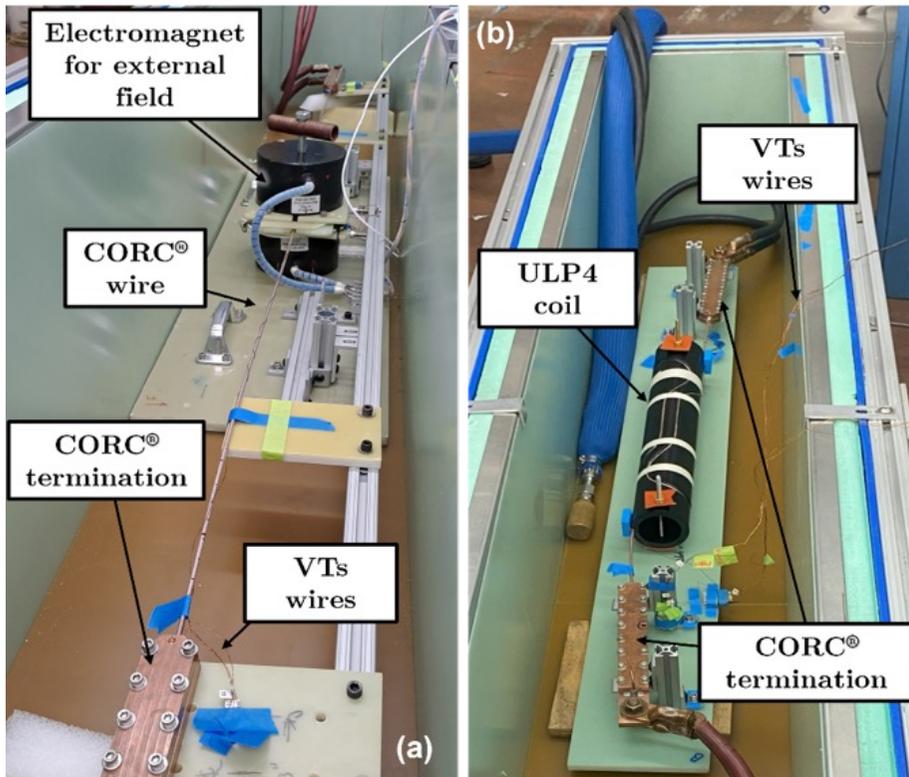
- **Magnet design:** Adoption of the new "**Uni-layer**" configuration to overcome the minimum bending radius limits of ReBCO-based wires, such as CORC, to enable the winding of small-aperture magnets with high magnetic efficiency and minimal I_c degradation.



- **Mandrel Design & Fabrication:** various designs and analysis among different mandrel materials to minimize differential thermal contraction w.r.t. the conductor at 77 K, and validation of a manual winding procedure for the complex 3D groove trajectory.

Development of the first HTS uni-layer magnet prototype (2/2)

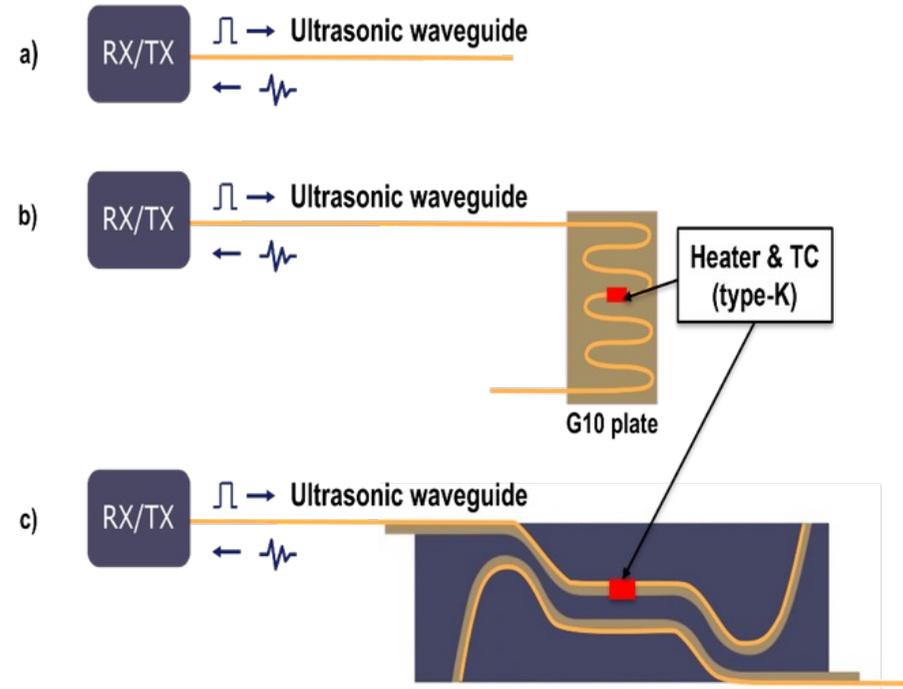
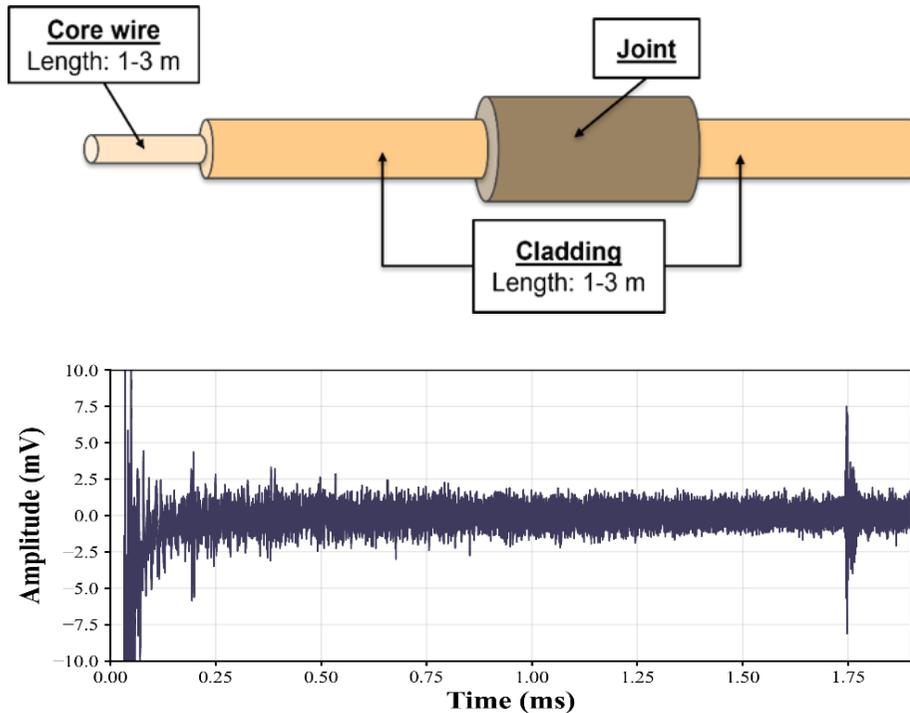
- **Simulation & Experimental Validation:** Characterization of the coil at 77 K, comparing the I_c of the straight wire vs. the wound coil to assess I_c degradation



- **Minimal Degradation:** Measurements showed an I_c degradation of only **9.62 %** (w.r.t. short sample limit), comparable with previous tests with the same cable on CCT magnets tested at LBNL.

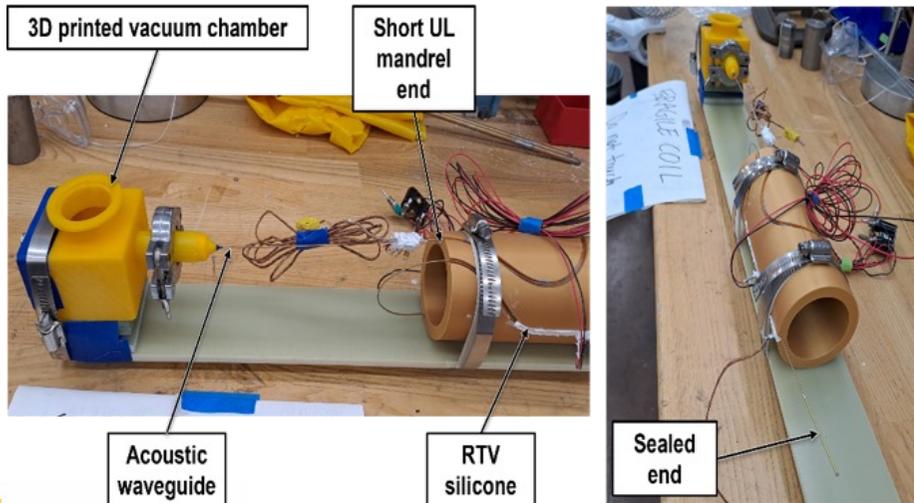
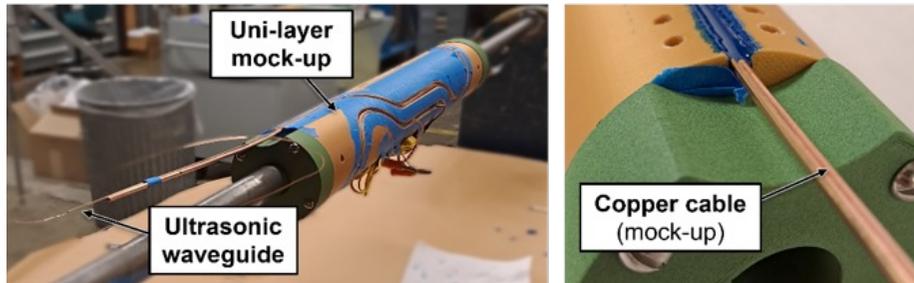
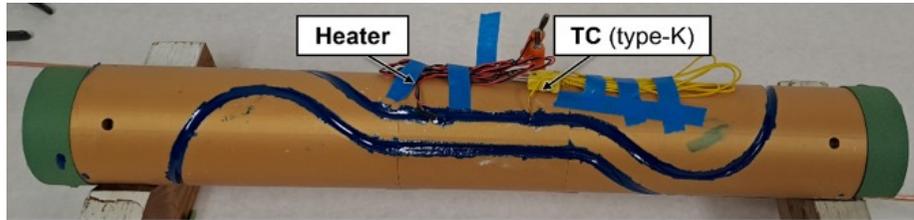
Ultrasonic waveguide for quench detection and localization (1/2)

- **Acoustic Thermometry:** Distributed sensing based on sound velocity temperature dependence, using **cross-correlation** to monitor time-of-flight shifts induced by thermal hotspots.

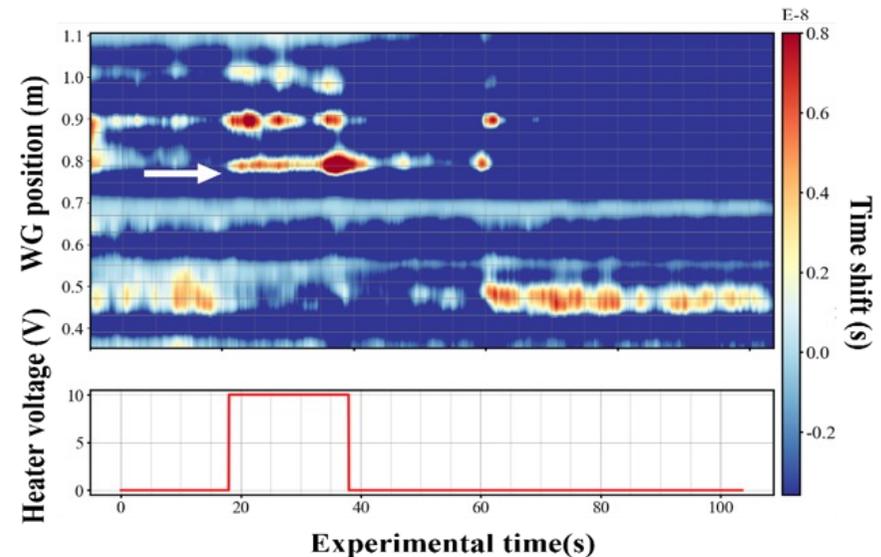


- **"Non-Leaky" Waveguide Design:** Development of a tailored waveguide featuring a **Bronze core** and **Brass cladding** to mechanically decouple the core from the coil structure, enabling low-loss signal propagation. Tests were carried out in three different experimental scenarios.

Ultrasonic waveguide for quench detection and localization (2/2)

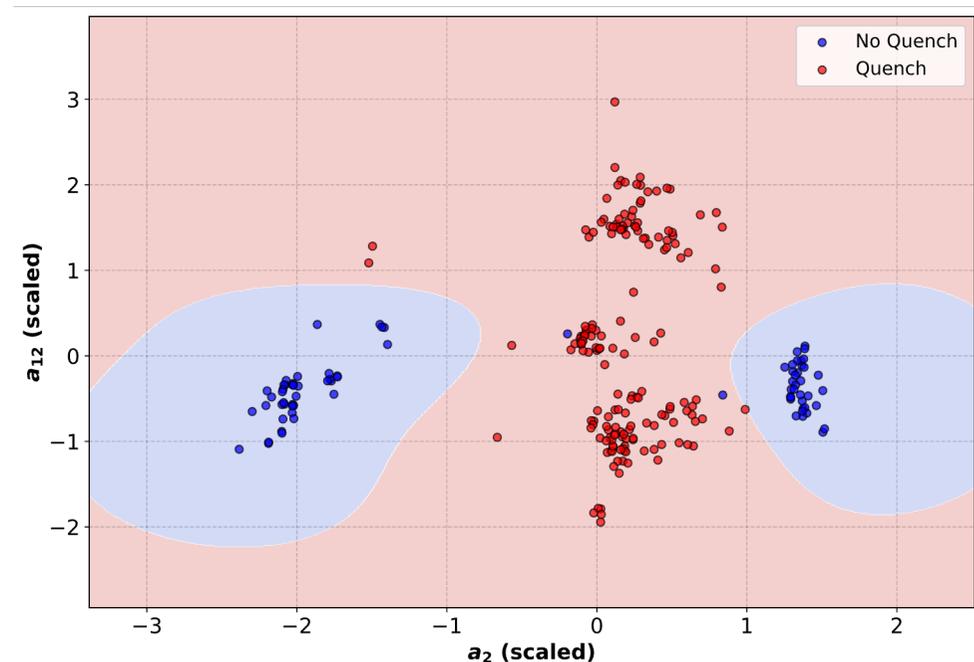
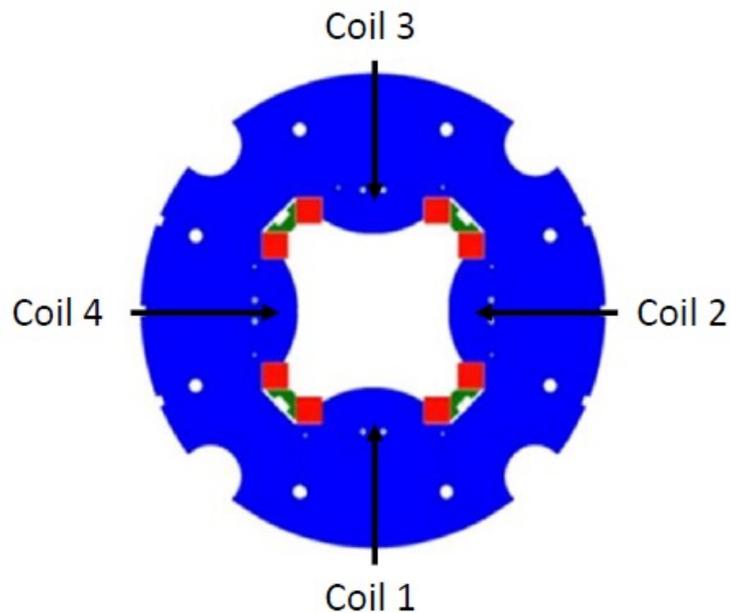


- Initial integration in a copper mock-up coil yielded no results due to poor thermal coupling. A **simplified, reduced-length setup** was then implemented to successfully isolate thermal effects
- **Localization Accuracy:** successfully localized the heat source with temperature rises as low as 0.1 K an resolution on the order of 1 cm.



Quench analysis of Quadrupole Magnets via Machine Learning (1/2)

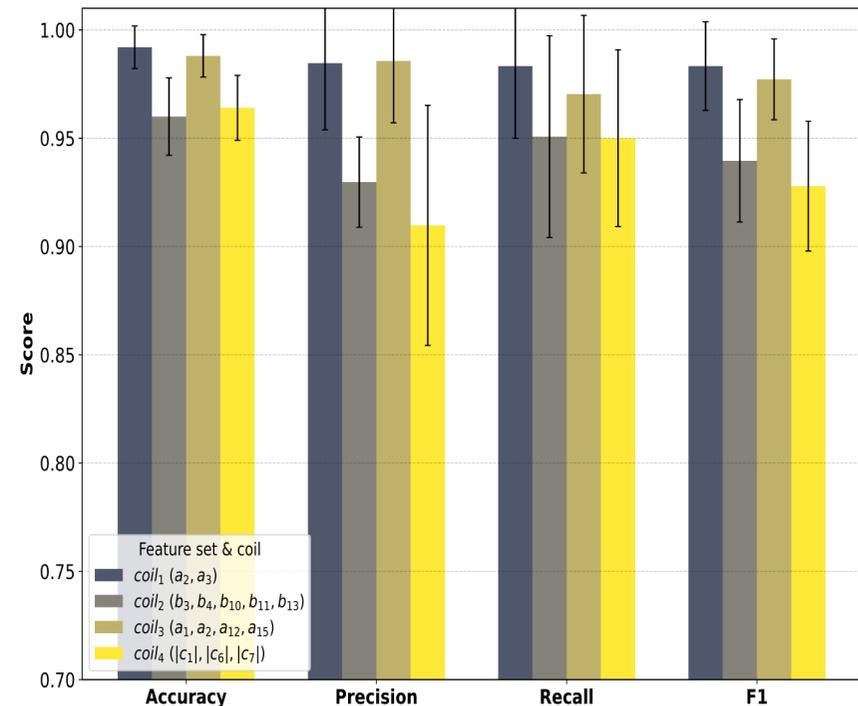
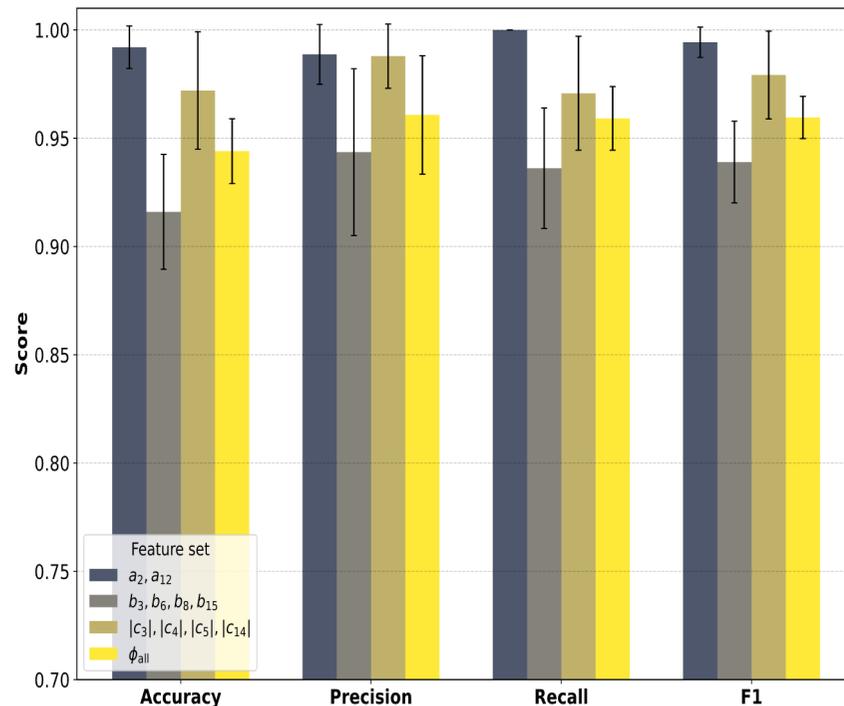
- **ML-based Diagnostics:** Application of ML to detect and localize quenches in the **HL-LHC Skew Quadrupoles** by analyzing **residual magnetic field harmonics**
- **Data Acquisition:** Harmonics up to the 15th order (a_n, b_n, c_n, ϕ_n) were extracted via **FFT analysis** of magnetic flux signals acquired by a **rotating coil** inserted into the magnet bore after discharge



- **Algorithm Implementation:** Use of Support Vector Classifiers (SVC) with non-linear kernels to model the complex decision boundaries in the harmonic feature space

Quench analysis of Quadrupole Magnets via Machine Learning (1/2)

- **Validation Performance:** the model trained on A_n harmonics achieved **99.2 % accuracy**
- **Blind Test:** a perfect scores (**100.0 % accuracy and Recall**) was achieved for detection



- **Localization:** The four independent SVCs identified the specific faulty coil with an accuracy > 98.0 % on the blind test set, showing superior accuracy compared to the baseline.
- **Benchmark vs. Interpretable Models:** Comparative analysis showed that SVCs achieves similar performances compared to interpretable models (e.g., Decision Trees) in generalization capabilities, providing a more reliable diagnostic tool.