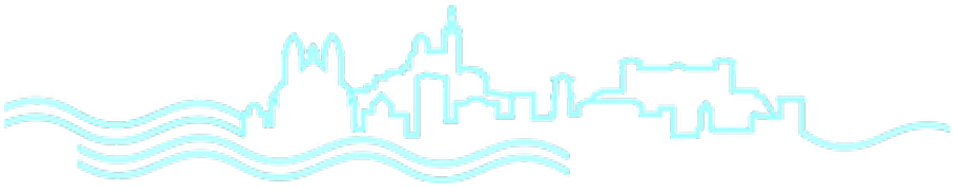

Contribution ID: **772** Type: **Poster**

Scalable Readout Architecture for Large-Scale Quantum Sensor Arrays in Fundamental Physics

Wednesday 9 July 2025 19:10 (17 minutes)

Modern experiments in particle, astroparticle physics, and cosmology, particularly those probing for New Physics, are increasingly relying on quantum sensors to achieve unprecedented sensitivities. These include efforts to determine the absolute neutrino mass scale, search for neutrinoless double beta decay, detect potential dark matter candidates, or measure the B-mode polarization of the cosmic microwave background (CMB) to test the inflationary model of the early universe. Achieving these goals requires the development and simultaneous readout of large-scale arrays of cryogenic detectors, often ranging in the tens or hundreds of thousands. Frequency-Division Multiplexing readout techniques, such as microwave SQUID multiplexing, are critical enablers of these ambitious programs.

To support this, we are developing the Quantum Interface Controller (QIC), a modular and scalable readout system shared across several experiments in these domains. This technology is also used in quantum computing since superconducting qubit characterization and control require similar high-fidelity microwave-based instrumentation. This system supports full-stack end-to-end signal processing. The room-temperature electronics perform digital synthesis of the required microwave tones and implement real-time demodulation of the detector signals using FPGA-based firmware and a user-friendly software stack to process the results.

We present the architecture of this multi-purpose readout system, discuss the modular implementation of the signal processing firmware, and describe the supporting software tools developed for control and data handling. One part of the system is the CryoDE (Cryogenic Detector Emulator), a digital detector twin integrated directly into the firmware, which enables hardware-in-the-loop (HIL) testing of the entire signal processing chain. This feature allows for rapid iteration and validation of firmware and system performance without requiring access to the full cryogenic infrastructure. This common readout infrastructure is adaptable to the needs of each experiment; currently, it is being deployed in support of the ECHo (neutrino mass), BULLKID-DM (dark matter), and QUBIC-upgrade (CMB) experiments, improving development efficiency and long-term maintainability. This contribution provides an overview of the current status of the data acquisition systems within these efforts and will show selected results of recent tests with prototype detector systems.

Secondary track

T12 - Data Handling and Computing

Author: Dr ARDILA-PEREZ, Luis E. (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT))

Co-authors: Mr CROVO PÉREZ, Daniel A. (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Prof. SIMON, Frank (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Dr SALUM, Juan M. (Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Comisión Nacional de Energía Atómica (CNEA) - Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Dr FERREYRO, Luciano P. (Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Comisión Nacional de Energía Atómica (CNEA) - Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Mr SCHELLER, Lukas (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Mr GARCIA REDONDO, Manuel E. (Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Comisión Nacional de Energía Atómica (CNEA) - Institute for Data Processing and

Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Prof. PLATINO, Manuel (Instituto de Tecnologías en Detección y Astropartículas (ITeDA), Comisión Nacional de Energía Atómica (CNEA)); Mr FUCHS, Marvin (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Dr SANDER, Oliver (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Mr GARTMANN, Robert (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT)); Mr MUSCHEID, Timo (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT))

Presenter: Dr ARDILA-PEREZ, Luis E. (Institute for Data Processing and Electronics (IPE), Karlsruhe Institute of Technology (KIT))

Session Classification: Poster T15 (Quantum technologies in HEP (special topic 2025))

Track Classification: T15 - Quantum technologies in HEP (special topic 2025)