Snowmass2021 - Letter of Interest

Superconducting Detector Facility for HEP Science

Thematic Areas:

■ (IF1) Instrumentation: Quantum Sensors
■ (IF2) Instrumentation: Photodetectors

Contact Information:
Thomas Cecil (Argonne National Laboratory) [cecil@anl.gov]

Authors: Thomas Cecil (Argonne National Laboratory), Clarence Chang (Argonne National Laboratory), Marharyta Lisovenko (Argonne National Laboratory), Gensheng Wang (Argonne National Laboratory),Volodymyr Yefremenko (Argonne National Laboratory)

Superconducting devices have a rich history in High Energy Physics (HEP). HEP scientists developed the Transition Edge Sensor (TES) which has been deployed in WIMP Dark Matter searches[1] (using hundreds of TES on a large crystal in order to perform event reconstruction from athermal phonons) and measurements of the Cosmic Microwave Background (e.g. the SPT-3G experiment[2] utilizes a focal plane of over 10,000 CMB bolometers to search for signs of inflation in the polarization of the CMB). Another HEP application of superconducting circuit technology is the ADMX experiment[3] which uses a SQUID to amplify the potential microwave signal produced from axion Dark Matter interacting with a magnetic field.

Because the typical energy scale for superconductivity is the gap energy, $O(10^{-4})$ eV, detectors and devices that exploit superconductivity are capable of measurements that are impossible using other technologies, which have characteristic energy scales of $O(1)$ eV. Superconducting detectors and devices are especially well suited to applications where the signal is rare or faint making sensitivity critical. Looking towards the future, superconducting detectors, devices and circuits will continue to play a critical role across a number of HEP science thrusts. Examples include:

- **Cosmological studies of the early universe:** the CMB-S4 experiment will require ∼500k TES detectors (an order of magnitude more than previous experiments)[4] and cosmic surveys using Line Intensity Mapping techniques will utilize KIDs

- **Searches for low-mass Dark Matter particles:** superconducting nanowire single photon detectors (SNSPDs) with sub-eV threshold are being explored for direct detection of sub-GeV Dark Matter,[5] and low threshold TES detectors for calorimetric measurements of photons, light, heat, and or evaporated Helium atoms are being developed for light Dark Matter particle searches[6–8]

- **Searches for Axion Dark Matter:** superconducting qubits are being used in connection with RF cavities to search for axion Dark Matter,[9] and THz-photon counting kinetic inductance detectors (KID) in conjunction with quantum readout techniques are proposed to look for wide band axion Dark Matter detection[10]

- **Neutrinos:** low threshold TES detectors are being developed for use as light detectors for background discrimination in neutrino-less double beta decay searches[11] and as thermistors for calorimetric measurement of Coherent Elastic Neutrino Nucleus Scattering using dielectric or superconducting crystals[12]

HEP experiments utilizing superconducting detectors and devices require the custom creation of complex detectors integrated into specific experiment configurations. Challenges are associated with fabricating these complex integrated devices while maintaining the required control of the underlying materials properties. Some technical goals are realizing lower detection thresholds, larger collecting areas, and increased integration of detector components. For example, ultra-low threshold detectors require superconductors with low transition temperatures (approaching 10 mK). There are few options for elemental superconductors in this range, but many techniques (superconducting - normal metal bilayers, magnetic doping, etc) can be used to custom tune the transition temperature to the desired value. Large collecting areas require the use of either large arrays of small detectors (e.g. using SQUID multiplexers or the inherent frequency multiplexing of KIDs) or large collecting structures to trap the signal of interest and funnel it to the detector. KID-based on chip spectrometers for LIM will combine spectrometer, detector, and readout components on a single chip, requiring processes with multiple layers of diverse materials with well managed interfaces.

A Superconducting Detector Facility would provide an important capability for advancing the types of superconducting technologies discussed above. Such a facility would have a large spectrum of well-controlled and dedicated tools for thin film synthesis and processing together with multiple methods for superconducting materials characterization.

References

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