COVER PAGE

Project Title: DOE-FAIR: Cryogenic Charge Amplifiers for Sub-GeV Dark Matter Detectors	
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Principal Investigator Information: Arran Phipps	**Recipient Organization:** California State University East Bay Foundation 25976 Carlos Bee Blvd Hayward, CA 94542-1602 Country: USA **UEI:** GEXJV1ZLVDM8

ACCOMPLISHMENTS

Major Goals and Objectives

This two-year project is developing a high-performance cryogenic amplifier system for detecting individual electrons in dark matter experiments. The system is based on commercial CryoHEMT transistors and includes both cryogenic and room-temperature electronics. It is primarily designed to support detectors made from novel materials that could be sensitive to light (sub-GeV) dark matter particles - an area of increasing scientific interest. The final product is a complete high-resolution charge amplifier system easily adaptable to any insulating cryogenic detector material which produces charge excitations, with applications beyond dark matter detection.

The primary goal for Year 1 was to establish full testing capability at Cal State East Bay (CSUEB), a primarily undergraduate institution, and begin assembling the full cold + warm amplifier system. Prior to this project, all testing of the amplifier was performed at SLAC National Accelerator Laboratory (SLAC). Achieving these project goals enables independent development and testing, without relying solely on national laboratory infrastructure.

Technical Approach

The final amplifier system consists of two parts:

(1) A cryogenic two-stage front-end, which operates at temperatures near 25 milliKelvin, using a low-capacitance CryoHEMT transistor mounted next to the detector. A secondary CryoHEMT transistor mounted to the 4 Kelvin stage of the cryostat provides voltage amplification.

(2) A warm electronics board, which supplies clean bias voltages, bias current monitoring, voltage gain calibration, additional signal amplification, and includes an “active reset” feature to improve overall amplifier performance.

The system is validated by two independent methods, generally using silicon samples as a well-understood detector medium. First, the output voltage noise of the amplifier is recorded and used to estimate the charge resolution via a calibrated voltage gain measurement. Second, controlled light pulses from an optical fiber incident upon the detector substrate create electron pulses which are then amplified. The charge resolution can be determined from the dependence of amplifier output pulse height on incident light pulse height. Both methods independently determine the smallest number of electrons the system can detect with confidence, and agree within error.

The warm and cold electronics are developed and tested at CSUEB, however the CSUEB cryostat temperature is limited to 4K. Access to sub-Kelvin temperatures is provided by collaborators at SLAC.

Progress and Accomplishments

During this reporting period, the following major milestones were achieved:

- The CSUEB cryostat was retrofitted to test both base temperature and 4K cryogenic amplifier boards using identical wiring to the SLAC cryostat. The system is now electrically equivalent to the SLAC cryostat, enabling seamless swapping of hardware between institutions.

- A solder reflow oven has been acquired, commissioned, and is in use. CSUEB students are able to quickly populate electronics boards in-house, allowing for rapid prototyping and development.

- A copy of the CryoHEMT amplifier for dedicated testing at CSUEB was fabricated. The CryoHEMT amplifier was successfully operated at CSUEB for the first time. Parts are on-hand to fabricate additional amplifier boards as needed.

- A precision room-temperature instrumentation amplifier was designed, assembled, tested, and coupled to the CryoHEMT amplifier. The room temperature amplifier is crucial for ensuring system performance is limited by the cryogenic stages. The amplifier was shown to have excellent performance and is incorporated into the new warm electronics board.

- Fiber-optic calibration tests conducted at SLAC demonstrated sensitivity to charge signals as small as ~20 electrons in silicon. The warm readout card used for these tests is passive, relies on several pieces of external equipment, and does not support active reset. The resolution is expected to improve with the new warm electronics board.

- A limiting noise source was identified: the 100 MΩ resistors used as a passive reset do not cool effectively to base temperature and introduce excess noise. This also prevents full characterization of the intrinsic CryoHEMT noise. Active reset removes the need for these resistors.

- A new warm electronics board design was completed. The design integrates clean voltage biasing for both detector and amplifier, room temperature post-amplification, and active reset functionality.

- Board population and testing of the new electronics at CSUEB is scheduled before the end of the current project year.

These accomplishments satisfy the primary Year 1 objective of enabling amplifier development and testing at CSUEB.

Plans for Next Reporting Period

In Year 2, the project will:

- Complete testing of the new warm electronics board. Identical copies will be produced for both CSUEB and SLAC. Any necessary revisions or improvements will be included in a second iteration, scheduled to be produced during the second half of Y2.

- Implement active reset in the cryogenic amplifier system. This will be thoroughly vetted and tested at CSUEB. The active reset removes the 100MΩ resistors (used for passive reset) which are currently limiting our ability to fully characterize the CryoHEMTs.

- Current and voltage noise characterization of the input CryoHEMT as a function of bias power. These measurements are currently being prevented by the poor thermalization of the 100MΩ resistors, solved by the active reset.

- Current and voltage noise characterization of lower-capacitance input HEMT replacements. We have acquired additional CryoHEMT gate geometries which have even lower input capacitance than the geometry currently in use. These are expected to further improve charge resolution, potentially approaching the single-electron level.

- Perform calibration tests of silicon sample detectors utilizing active reset and new warm electronics boards at both CSUEB and SLAC.

- Production of the final cryogenic amplifier hardware and warm electronics for future research use.

Training and Professional Development

Three undergraduate students were directly supported by the grant in Year 1. They participated in electronics design and review, PCB layout, PCB fabrication, cryostat retrofitting, amplifier testing, and data analysis. Students also contributed to weekly research meetings, presented at conferences, and gained exposure to cryogenic systems, generic laboratory electronics, and experimental techniques in particle detection. Students assisted in the installation and testing of the

amplifier at SLAC, gaining exposure to work at a national laboratory. Graduate students and postdoctoral scholars at SLAC also assisted in detector testing and analysis. These skills position them well for graduate programs and careers in technical industries.

Dissemination to Communities of Interest

Project results were shared through the following activities:

- PI Phipps gave an invited seminar at Sacramento State University titled “Searching for Light Dark Matter with Narrow-Gap Semiconductors.”
- Undergraduate and graduate students presented their research at the APS Global Summit and LTD-20 (International Workshop on Low Temperature Detectors).
- An undergraduate researcher is scheduled to present at the CPAD 2025 conference.
- A seminar at Lawrence Berkeley National Laboratory (LBNL) given by PI Phipps is scheduled for November 2025 to share additional results.
- Undergraduate researchers are scheduled to present at the APS Global Summit 2026.
- Other members of the SPLENDOR collaboration also regularly give talks and seminars that reference this amplifier system and future improvements.

These presentations reached the dark matter detection, cryogenic electronics, and detector development communities, while highlighting the research contributions of a primarily undergraduate institution.

PRODUCTS

The products shown below include only Publications with a 'Published' status and Intellectual Properties with a 'Granted' status. Products with other statuses are not included in this report. The Revision Type indicates whether a product is New (newly added), Updated (existing product modified), or No Change (existing product reported without modifications) during the current budget period. Note that 'Updated' statuses may appear more frequently as products progress through the publishing process. All products listed have been reported for the current project period of this award.

PUBLICATIONS

There are no publications to report.

INTELLECTUAL PROPERTIES

There are no intellectual properties to report.

PARTICIPANTS AND OTHER COLLABORATING ORGANIZATIONS

The table below only contains participants who have identified an affiliation with the Awardee Institution. Participants from any associated subawards may not be included in this count.

PARTICIPANTS DETAIL

Project Role	Number of People	Total Person Months Worked
Principal Investigator/Project Director	1	4
Undergraduate Student	3	6
Total Responses	**4**	**10**

PARTNERS DETAIL

Partner: SLAC National Accelerator Laboratory, Menlo Park, CA, USA

IMPACT

Impact on the Development of the Principal Discipline

This project advances the field of experimental dark matter detection by enabling the development and characterization of a modular, high-resolution charge amplifier designed for sub-GeV dark matter searches. By demonstrating cryogenic operation, thermal noise-limited performance, and compatibility with narrow-gap semiconductors, the amplifier system supports ongoing efforts to extend dark matter sensitivity into the meV-GeV mass range. The work also contributes to the broader discipline of cryogenic sensor readout through detailed noise modeling and validation against photon-based calibration.

Impact on Other Disciplines

Beyond dark matter detection, the amplifier architecture is directly applicable to other fields requiring ultra-low-noise charge sensing, including quantum sensing, condensed matter physics, and astrophysical instrumentation. The system's compatibility with high-impedance detectors and its adaptability to different substrates broaden its relevance across low-temperature experimental science.

Impact on Infrastructure

The project significantly enhanced research infrastructure at Cal State East Bay (CSUEB), a primarily undergraduate institution. Local cryostat upgrades, wiring retrofits, and data acquisition system development enabled in-house amplifier testing for the first time. These upgrades support future research programs in cryogenic electronics, detector development, and quantum measurement. The amplifier system was also tested at SLAC, establishing a reproducible cross-institutional configuration and strengthening long-term collaboration.

Impact on Technology Transfer

While no formal technology transfer agreement has yet been established, discussions are underway with researchers at Arizona State University, Caltech/JPL, and Washington University in St. Louis to adapt the amplifier system for Cold Electron Bolometers (CEBs) - devices used in photon detection and cryogenic astrophysical sensors. These discussions may inform future collaborative development and broader application of the amplifier design in both government and academic research settings.

Impact on Commercial Technology or Public Use

The amplifier's modular design and demonstrated performance make it a promising candidate for future integration into compact readout platforms for rare-event detectors and quantum devices. The architecture could inform future commercial instrumentation in cryogenic electronics and low-noise analog front-ends. At present, there is no start-up or commercial license associated with this work, but its publication and active dissemination are encouraging further interest in deployment outside of dark matter applications.

Impact on Society Beyond Science and Technology

As part of a hands-on research experience at a public, primarily undergraduate institution, the project helps broaden participation in advanced scientific instrumentation and promotes STEM workforce development. Students trained under this project gained technical and research experience that directly supports national scientific capacity and prepares them for careers in high-tech industry and graduate-level research.

Impact on Human Resources Development

The project supported three undergraduate researchers, all of whom participated in experimental development, data analysis, and professional dissemination. These experiences provided critical early exposure to experimental physics and mentorship in a research environment. In addition, graduate students and postdoctoral researchers at SLAC contributed technical expertise and collaborative support, strengthening knowledge transfer across institutions.

Foreign Spending

A portion of the award budget - approximately 8% - was used to purchase CryoHEMT transistors from a supplier based in France. This constitutes the only foreign expenditure under this award.