EIC Detector R&D Progress Report

Project ID: eRD28
Project Name: Superconducting Nanowire Detectors for the Electron Ion Collider
Period reported: from October 1, 2020 to March 5, 2021
Project Leader: Whitney Armstrong
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Abstract

Superconducting Nanowire Single Photon Detectors (SNSPDs) have become the dominant technology in quantum optics due to their unparalleled timing resolution and quantum efficiency. We are proposing to transform this technology into a particle detector for the EIC. Recently, we have demonstrated detector operation in magnetic fields greater than 5 T at high rate with high efficiency. Leveraging these results and detector timing resolution as low as $\lesssim$ 20 ps, this project will produce a small (mm^2) superconducting nanowire pixel array for detecting high energy particles. This first of its kind detector will have the flexibility to be used in multiple far forward detector systems, and will extend the scientific reach of the EIC.

Introduction

Good far-forward recoil acceptance is critical for the fully exclusive electro- and photo-production measurements of J/ψ and Υ ranging from threshold to large photon-nucleon invariant mass, as outlined in the EIC White Paper and Yellow report. The measurements are at the heart of answering questions about the gluonic contribution to the origin of the proton mass and spin. Plans at providing full exclusivity detection using conventional technologies are part of the Roman Pot development in eRD24.

The superconducting nanowires are a detector technology that has almost all metrics far superior to conventional semiconductor technology, except for the current drawback being the relatively small area of the detector, which makes it a good candidate for an alternative in, e.g. far-forward detectors, such as the before mentioned Roman Pots. Because this technology has not been previously used in nuclear physics, eRD28 was approved to deliver a proof of concept particle detector and test it in a high-energy proton beam, although only at a small faction of funding of what is truly necessary for this task.

Since the original approval of the eRD24, new applications for nanowire within EIC, as suggested by the review committee, have been identified, e.g. as part of the Compton polarimeter, where the necessary extreme position resolution and radiation hardness can be easily covered by this technology.

Past

Milestones of this project at minimal funding (only 25% of which has been approved) were:

1. Design and procure a portable testbed system for potential future deployment at Fermilab's test beam facility.
2. Test performance of superconducting nanowire devices as particle detectors in-house using sealed sources
3. Fabricate small, few-pixel detector array.
4. Characterize device performance with a high-energy proton beam

We procured and assembled a portable cryostat (see Figure 1), designed to readout up to 8 high-frequency channels and 26 low frequency/DC channels, that can hold at base temperature of 3 K under load. The jacket of the cryostat is compatible with most common vacuum chamber fittings and can be readily deployed at external facilities.

Due to Laboratory closure because of COVID-19, items 2. and 3. are delayed, where testing of single-pixel detectors with sealed sources is currently in progress and fabrication efforts are suspended until restrictions are further relaxed. Deliverable 4. is also dependent on work restrictions at the test beam facility at Fermilab.

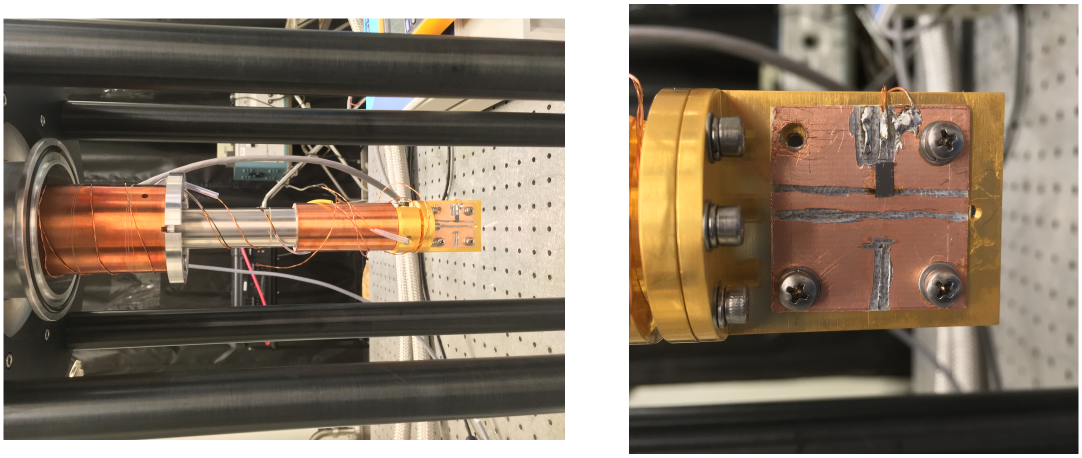

Figure 1: Left: The portable cryostat with vacuum sleeve removed, exposing the cold finger capable of stable operation at 3 K. Standard flange compatible with most common vacuum systems (including beam-line) visible towards the top of the image.
Right: Close-up view of the portable cryostat cold finger with a prototype board holding a nanowire detector (gray chip, center-right). This configuration of board and holder is meant for sealed source particle and light detection, and is not representative of the design for beamline detector.

Future

We plan to continue with the current testing of simple devices using sealed sources in the newly-designed test bed and gather data which will be used to optimize their design for medium-to-high-energy particle detection.

Preliminary results and meso-scale supercondutor simulations indicate, that the microplasma track of a charged particle is sufficiently large to trigger a transition through the whole cross-section in a unbiased nanowire (see Figure 2), completely bypassing the avalanche process that is usually necessary to detect photons. This means that the requirements for feature sizes of nanowire *particle* detectors are significantly less stringent than for detection of photons. This enables us to use higher-throughput microfabrication techniques (e.g. photolitography instead of electron beam lithography for device patterning), increasing our device fabrication capabilities by several orders of magnitude. Fabrication of devices optimized for particle detection using our simulation data and results of sealed source testing will commence as soon as Laboratory's COVID-19 restrictions are lifted.

We will access to the test beam facilities with other tests that the group is performing on UFSD and thus, we will be able to reach deliverable 4. shortly after we have fabricated the first generation of optimized nanowire particle detectors.

Our group has also formed a collaboration with Fermilab's ASIC group that works on many-channel superconducting nanowire detector readout for quantum communication applications. Deliverables of this project can be leveraged to have a fully fledged extreme far-forward detector or

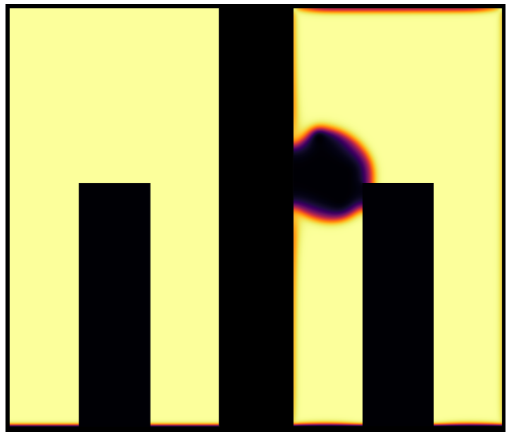

Figure 2: Simulation of a unbiased superconducting nanowire detector section during a 5 MeV α-particle detection event. Color represents the square of the superconductor order parameter (proportional to the density of superconducting carriers).

Compton polarimeter subsystem ready for day-1 operation.

Manpower

- Whitney Armstrong 0.2 FTE not funded from EIC R&D
- Tomas Polakovic: 1.0 FTE not funded from EIC R&D
- Valentine Novosad 0.2 FTE not funded from EIC R&D
- John Pearson 0.1 FTE not funded from EIC R&D

The EIC R&D funding has been minimal ($8.8K) and far from the need to carry this project however, we are committed to see this project through.

External Funding

Internal base fund is covering the funding shortage to complete the proposed tasks.

Publications

Given that the proposal is in its first year and large part of work was suspended because of COVID-19, no publications related to the this project are available.