Accelerator and Quantum Detector Cryogenics R&D

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Background

The Particle Physics Community Planning Exercise will map the road for the U.S. Particle Physics community in the upcoming decades on. As part of this exercise, there is an urgent need to develop a research plan for Accelerator and Quantum Detector Cryogenics technical solutions to support Particle Physics community work on future colliders and detectors.

Among the possible future mega-science projects are the International Linear Collider, Future Circular Collider, and Muon Collider. These and other similar colliders utilize cryogenic technology in both accelerators and detectors and will require considerably higher capacity cryogenic plants than even systems at the LHC scale.

In the field of quantum detectors, cooling technologies have seen rapid development in industry during the previous decade, driven largely by commercial quantum computing research users. While this development has been impressive, there are several areas of improvement in scale and efficiency of operation in which the National Laboratories are uniquely placed to investigate, especially in conjunction with the National Quantum Initiative Centers.

This LOI outlines the challenges for cryogenic technology. An upcoming contributed paper will elaborate on these challenges in more details and present the proposed research plan.

Large-scale Cryogenic Systems

The list below is our perception of a need to address issues in cryogenic technology areas associated with the large helium and superfluid helium cryogenic systems for large colliders. Some of the challenges in the construction of large systems are as follows:

- How do we improve large cryogenic system efficiency?
- How do we minimize the maintenance time of cryogenic system and so maximize the system up time?
- How do we improve prediction of transient modes in large systems?

To address these issues, possible specific areas of research include:

- Thermodynamic cycle optimization for large and very large superfluid helium systems;
- Warm helium compressor systems thermodynamic efficiency improvements;
- Control of parallel operation of multiple superfluid helium refrigerators;

- Technology and engineering solutions for key components of large cryogenic system;
- Development of engineering tools for cooldown and other transient modes simulation.

Sub-Kelvin and Millikelvin Cryogenic Systems

Challenges for cryogenic superconducting and quantum detectors are:

- How can we construct more powerful cooling systems while reducing the use of scarce Helium-3 resources?
- How can we reduce the construction costs of large dilution refrigerator systems?
- How can we improve the efficiency of the refrigerator systems, particularly in relation to electrical input power?
- How do we design filtration and circulation systems to minimize the chances of inadvertent blockage of the circulation system and maximize the up time of the system?

To address these issues, specific research areas include:

- Investigation of alternative heat exchanger designs, construction techniques, and materials. These could include the use of copper powders and 3D printed structures;
- Improvements to the design and operation of 4-K class mechanical cryocoolers, particularly in the design of the driving compressors or alternative thermodynamic cycles;
- Development of small liquid helium or superfluid cryogenic plants that could obviate the need to use low-efficiency 4-K pulse tube coolers;
- Development of robust pumping and filtration system to minimize the introduction of contaminants into the helium stream.

Conclusion

Addressing these and other technical issues related to the development of cryogenic supporting technologies will be vital in the continued growth of systems for high energy physics experiments.