Letter of Intent for Snowmass 2020: Research and Development to Advance Technology of Strong Cooling of High Energy Hadron Beams

Yuhong Zhang, Steve Benson, Andrew Hutton, Geoffrey Krafft, Fanglei Lin and Robert Rimmer, Thomas Jefferson National Accelerator Facility; Valery Lebedev and Sergei Nagaitsev, Fermi National Accelerator Laboratory; Michael Blaskiewicz, Jorg Kewisch and He Zhao, Brookhaven National Laboratory

Next generation energy-frontier hadron-hadron or hadron-lepton colliders could benefit greatly from the availability of extremely high intensity hadron beams. One of the advanced techniques for generating these intense hadron beams is strong cooling, a process that enables a substantial reduction of the 6D phase space volume a hadron beam occupies. A successful example is cooling of antiprotons in the Fermilab recycler by a 4.3 MeV DC electron cooler [1]. Several recent projects and proposals, including an electron-ion collider, which was recently approved by US DOE, also employ strong cooling of hadron beams for boosting key performance parameters of the facilities (for example, high integrated-luminosity and long beam-lifetime).

Presently, strong cooling of high energy hadron beams is a topic of active research and development worldwide. One of the cooling mechanisms is electron cooling (in modern terminology called the incoherent electron cooling) in which the heat is transferred from a relatively hot hadron beam to a cold electron beam through many Coulomb collisions between hadrons and electrons. This cooling concept was proposed [2] and then experimentally tested half a century ago. It has since been employed in many facilities worldwide. Recently, several innovative cooling concepts based on electron cooling have been proposed and studied by a number of groups in the US to extend the cooling energy range. The R&D is aimed at the development of a high energy electron beam facility for electron cooling. Some of these new concepts are list below,

1. *Induction-linac based DC electron cooler* [3]
   This cooler concept calls for sending a pulsed, sub-micro-second long electron beam of ~100 A at 55 to 150 MeV into a small electron storage ring, where it circulates for more than ten thousand turns while cooling a stored hadron beam. The electron beam is generated from a thermionic gun and accelerated by an induction linac. The layout of this cooler is shown in Figure 1 (upper left). Few pass recirculation can be used to reduce the induction linac energy.

2. *An electron cooler driven by an ERL and a circulator ring* [4]
   This cooler concept utilizes a high charge source to provide a magnetized beam and an SRF linac to accelerate it to the target energy. To boost the beam current, a small cooler ring is added such that electrons circulate a number of times in the ring while cooling the hadron beam. After that, the spent electron beam is kicked out of the ring and a fresh beam is injected. The spent beam is sent to the same SRF linac for energy recovery and the recovered energy is used to accelerate the next bunch train. The layout of this cooler is shown in Figure 1 (upper right)

3. *A storage ring based electron cooler with many damping wigglers or a damping ring* [5,6]
   This type of coolers employs a storage ring for achieving high electron beam current, and utilizes synchrotron radiation damping to maintain high beam quality. It has two design configurations for boosting radiation damping. One is using many damping wigglers, as illustrated in Figure 1 (lower left). The other uses a second (damping) ring with a much higher energy but without requiring a wiggler, as illustrated in Figure 1 (lower right). An SFR energy recovery linac is used to manage the different energies of the two rings.

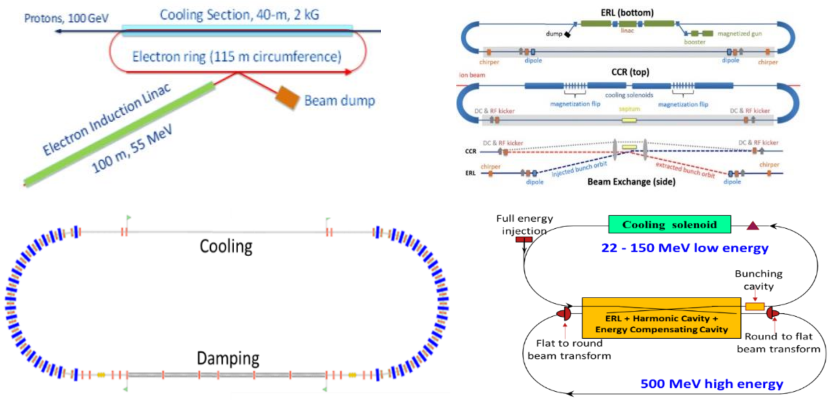

Figure 1: Schematic drawings of new design concepts of high energy electron cooling facility, they are induction-linac based cooler (upper left), ERL-circulator ring based cooler (upper right), single energy (lower left) and dual-energy (lower right) storage ring based cooler (lower right)

Presently, research and development of these new electron coolers is in the initial stage, largely at the conceptual level. The achievements to this day can be summarized as follows

1. Preliminary theoretical and simulation studies show these coolers could provide sufficient cooling performance to be interesting for a number of future hadron facilities or proposals.
2. A layout and preliminary optics design for each of the cooler proposals has been completed. Initial beam dynamics studies have not shown any show-stoppers.
3. Key technology R&D topics were identified, most of them are in the intermediate *Technology Readiness Levels* (TRLs) according to a recent community assessment [7], meaning they are in the stages between *technology development* and *technology demonstration*. TRL is a DOE system for evaluating the technical readiness of a project.
4. A number of technology R&D activities are underway.

In this letter of intent, we request support for the development of the next generation of cooling technologies for their potential applications in high-energy hadron facilities. Specifically, we propose to continue and expand the studies of this new generation of electron coolers. We propose the following near-term tasks for consideration:

1. Further development of the designs of the new coolers bringing them to a mature level, and conducting assessments periodically to review progress.
2. Expansion of the beam dynamics studies and exploration of key collective beam physics issues to demonstrate that the new coolers can be operated with the desired specifications.
3. Initiating development and prototyping of key components, performing bench tests, and eventually carrying out tests at existing hadron facilities.
4. Developing plans for test facilities for the most promising cooler proposals and preparing proof-of-principle demonstrations.

Reference:

1. "*Experimental Demonstration of Relativistic Electron Cooling*", by S. Nagaitsev, D. Broemmelsiek, A. Burov, K. Carlson, C. Gattuso, M. Hu, T. Kroc, L. Prost, S. Pruss, M. Sutherland, C. W. Schmidt, A. Shemyakin, V. Tupikov, A. Warner, G. Kazakevich, and S. Seletskiy, Phys. Rev. Lett. 96, 044801 – Published 30 January 2006

2. "*An effective method of damping particle oscillations in proton and antiproton storage rings*" by G. I. Budker, Soviet Atomic Energy. 22 (5): 438–440 (1967)

3. "*Conceptual Design Report: A Ring-Based Electron Cooling System for EIC*", By V. Lebedev, S. Nagaitsev, A.Burov,V. Yakovlev, I. Terechkine,A. Sainiand N. Solyak

4. "*Development of a Bunched Beam Electron Cooler Based on ERL and Circulator Ring Technology for the Jefferson Lab Electron-Ion Collider*", S.V. Benson, Y.S. Derbenev, D. Douglas, F.E. Hannon, A. Hutton, R. Li, R.A. Rimmer, Y. Roblin, C. Tennant, H. Wang, H. Zhang, Y. Zhang, Proceedings, 11th International Workshop on Beam Cooling and Related Topics (COOL2017)

5. "Ring-based electron cooler for the EIC at BNL" by He Zhao, M. Blaskiewicz and J. Kewisch https://indico.fnal.gov/event/20514/timetable/#20191007.detailed

6. "*Storage-ring Electron Cooler for Relativistic Ion Beams*", by F. Lin, Y.S. Derbenev, D. Douglas, J. Guo, R. Johnson, G. Krafft, V. Morozov, Y. Zhang, in Proceedings of 7th International Particle Accelerator Conference (2016), and https://arxiv.org/abs/1605.02594