Snowmass '21: Letter of Interest

The Center for Bright Beams as a model for accelerator research and education

Thematic Areas:
AF1: Beam Physics and Accelerator Education
AF7: Accelerator Technology R&D

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Abstract:
The Center for Bright Beams (CBB) is an NSF multi-institution interdisciplinary research center that addresses key challenges in accelerator science. CBB has a strong record of accomplishment relevant to accelerators ranging from large-scale colliders and X-ray sources to electron microscopes and industrial applications. CBB also educates early career accelerator scientists, with 30 current graduate students, 10 postdocs, and 20 undergraduates, some of whom will join the DOE workforce to advance accelerator facilities for HEP and beyond. This letter argues that CBB offers a useful model for accelerator research and education and identifies key ingredients for success.

Introduction

The Center for Bright Beams (CBB) is an NSF Science and Technology Center (STC) that joins scientists from eight universities, three national labs, and additional affiliated institutions for interdisciplinary research in accelerator science. While CBB has a finite lifetime, ending in 2026, it offers an example of effective university-based research that emphasizes student and postdoc education and broadens the pipelines into accelerator science. Accelerator research and education are important topics for Snowmass, and here we share relevant CBB experience.

Overview of the Center for Bright Beams

CBB joins Cornell University, the University of Chicago, the University of California at Los Angeles, the University of Florida, Brigham Young University, Arizona State University, Northern Illinois University, and University of New Mexico along with Berkeley Lab, Fermilab, SLAC and affiliates in order to increase the brightness of electron beams by two orders of magnitude while decreasing the cost and size of key accelerator technologies. CBB's research is highly interdisciplinary and relies for progress on the combined expertise of materials scientists, surface chemists, condensed matter physicists and accelerator physicists. CBB educates a diverse cadre of accelerator scientists with competence in allied disciplines. It is a synergistic complement to ongoing related activities at DOE multipurpose and accelerator labs.

CBB Research: CBB is organized into three interdisciplinary research themes, each with a broad range applications. The *Beam Production* team has identified the causes of the angular divergence and energy spread of electron emission and capitalized on that knowledge to demonstrate a photoemission source with record low mean transverse energy of 6 meV and 10 meV energy spread at low current [1]. It is now applying atomic-scale control of cathode materials to produce photocathodes with similar performance at high current, and to fabricate photocathodes capable of withstanding the adverse conditions of an operating electron gun. CBB has also begun work on photoemission sources with innovative geometries that can surpass current limits. The *Beam Acceleration* team is understanding the fundamental science of superconducting cavity surfaces in the presence of radio-frequency fields. It has used that knowledge to improve the methods for coating niobium cavities with Nb_3Sn so that for moderate gradients, cavity efficiency at 4.2K now exceeds that of the best niobium cavities today operating at 2K [2], [3]. It has also identified the mechanism by which nitrogen doping suppresses the formation of nanohydrides on the surfaces of niobium cavities [4]. CBB's long-term goal is to produce cavity surfaces "by design". The *Beam Dynamics and Control* team has demonstrated nanometer-scale normalized emittance in an ultrafast electron diffraction set-up [5], has shown in simulation that guns suitable for LCLS-II-HE can lower exit emittance through use of CBB photocathodes and parameter optimization [6] (*conserve*). It invented a simplification to optical stochastic cooling that should make it easier to realize for fast hadron cooling [7](*cool*). It also developed a new instrument to map the phase space occupied by a beam with unprecedented resolution [8], and is studying machine learning techniques to tune injectors [9], storage rings [10], and electron microscopes (*control*).

CBB Education: Despite the importance of accelerators, the U.S. educates few students to understand beam physics and accelerator science and technology [11]. Approximately a dozen U.S. universities offer doctoral degrees in accelerator science [12], together producing 15–20 doctoral accelerator scientists per year; but the estimated need at labs and in industry is four times that number [12]. CBB is helping to bridge this gap by training **~30 graduate students and 10 postdocs** in accelerator science. Each year, roughly 10 attend the U.S. Particle Accelerator School and many get hands-on accelerator training. Importantly, approximately half of CBB's students are in areas that the Department of Energy has identified as areas of critical need (*physics of large accelerators and systems engineering* and *superconducting radiofrequency accelerator physics and engineering*) [13]. In addition to their subject area training, CBB students integrate professional development with their research and become experienced in the practice of team science. CBB also involves **~20 undergraduates** in research each year, all of whom are considering accelerator science as a potential career path. CBB partners with minority-serving universities, such as University of Puerto

Rico at Mayagüez, Clark Atlanta University, Morehouse College, Chicago State University, and University of New Mexico in its research and educational programs, increasing the diversity of accelerator science and related disciplines.

Elements of success

University-based: CBB's basis in universities allows it to capitalize on the naturally interdisciplinary university environment. The expertise of condensed matter physicists, computer scientists, materials scientists, mathematicians and chemists is readily available as are the facilities needed for advanced materials fabrication and characterization. Moreover, this diverse group of university scientists brings accelerator research to high profile meetings such as the APS March meeting. The resulting increased visibility of accelerator science in the academic community has the potential to further strengthen U.S. accelerator research and expand the pool of young scientists entering the field. A very important benefit of university-based accelerator research is the training of students and postdocs prepared for careers in accelerator science.

Highly collaborative: CBB has benefited enormously from close collaboration across disciplines and across institutions. Close interplay between theory, experiment, sample characterization and performance tests results in a dynamic program that responds rapidly to discovery, and insights emerge from discussions among scientists with diverse expertise. Experimentalists at different institutions capitalize rapidly on new hardware advances, and cross-compatible designs allow for prototype testing in multiple environments.

On-campus hardware: The focus of CBB is on developing new methods that can be adopted at labs, in university facilities and by industry. While substantial progress can be made through fabricating and testing small samples, there is no substitute for testing and refining the new methods in working devices. In some cases, this can be achieved at facilities at national labs, as CBB did in testing low transverse energy photocathodes and knife-edge diagnostics at HiRES, while in others, progress is far faster with on-campus facilities such as UCLA's Pegasus, Cornell's photoemission guns and photoinjector, and the Cornell SRF facilities. On-campus hardware setups also provide students with hands-on accelerator experience.

Strong connection with knowledge transfer partners: CBB collaborates extensively with national labs and industry in order to benefit from their expertise and ensure that CBB methods are put into practice in lab and industry accelerators. For example, CBB partners with SLAC on machine learning for beam tuning, with SLAC, JLAB and Fermilab on SRF, with LBNL on photoemission sources, with Fermilab and ANL on nonlinear optics and beam cooling, and with IDES and Thermo Fisher on electron microscopes.

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