The Center for BRIGHTBEAMS

A NATIONAL SCIENCE FOUNDATION SCIENCE & TECHNOLOGY CENTER

NEWSLETTER

FALL 2020

Dear Friends of CBB,

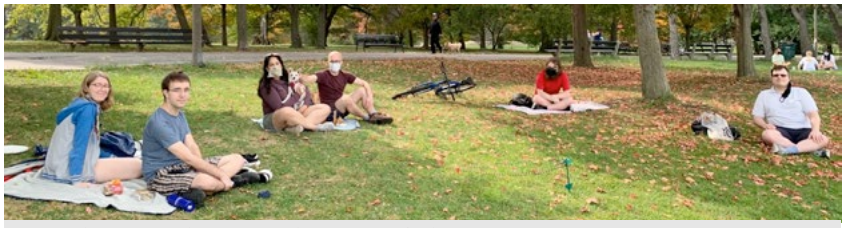
Recent months have been exciting ones at CBB. First, NSF has selected CBB for a second 5-year award for 2021 - 2026, allowing us to further advance our research and education. This marvelous outcome recognizes CBB's strong record of accomplishment in its first four years and its promise for the future. Go Beam Team! To learn more about our research plan, see the graphic on page 6 of this Newsletter.

In another development, CBB is pleased to welcome SLAC as a new member. SLAC brings exceptional expertise and capabilities and we look forward to close collaboration. CBB also welcomes Professor Sandra Biedron of the University of New Mexico, the leader of a major initiative at Brookhaven National Lab in ultrafast electron diffraction.

Last but not least, CBB has launched a new mentoring initiative for its grad students and postdocs. Under the plan, which was inspired by a student suggestion, each of their research projects is assigned two co-mentors with relevant interdisciplinary expertise. This initiative strengthens our mentorship, builds communication across the center, and offers affiliates an important new opportunity to contribute. Above all, the new program recognizes that close collaboration is the spark for CBB's greatest successes.

Stay well, Ritchie

J. Ritchie Patterson
Director of the Center for Bright Beams



CBB Chicago students picnicking at a safe distance.

CBB is the only center in the world that brings together an interdisciplinary team to address critical challenges in accelerator science.

It is a synergistic complement to ongoing related activities at DOE multipurpose and accelerator labs. CBB's knowledge generation and workforce development in concert with the development and implementation efforts at the national labs provide a winning strategy for ensuring continued U.S. leadership in this critical area of science and technology.

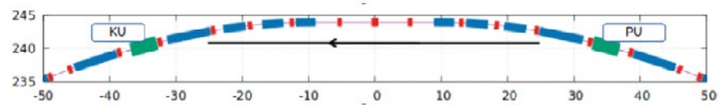
In This Issue

Research Highlights

Learn More About Research Applications and Relation to CBB Goals at cbb.cornell.edu

Optical Stochastic Cooling with an Arc-Bypass in CESR

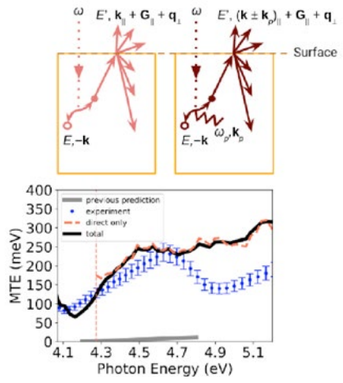
M. B. Andorf, W. F. Bergan, I. V. Bazarov, J. M. Maxson, V. Khachatryan, D. L. Rubin, and S. T. Wang



Advanced beam cooling techniques are being developed to address the challenge of luminosity degradation that occurs during a beam store in high brightness hadron and heavy-ion colliders. This paper explores a proposed test of a collider bypass design for one such technique -- Optical Stochastic Cooling -- in the Cornell Electron Storage Ring (CESR). Exploring methods of beam cooling with OSC to improve brightness in next generation particle colliders is a thrust of CBB and this paper is a good step forward towards our goal of demonstrating high-gain OSC in CESR.

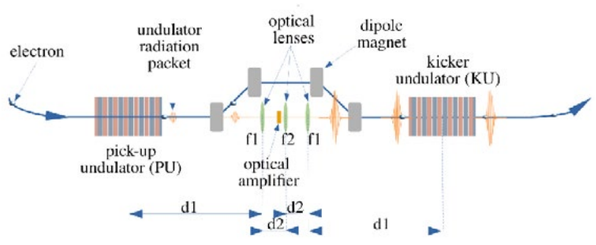
Ab Initio Many-body Photoemission Theory of Transverse Energy Distribution of Photoelectrons: PbTe(111) as a Case Study with Experimental Comparisons

J. K. Nangoi, S. Karkare, R. Sundararaman, H. A. Padmore, and T. A. Arias



Previous works predict that the (111) surface of PbTe is capable of producing high-brightness photoelectron beam with very low mean transverse energy (MTE) ≤ 15 meV., but experiments show otherwise. We develop a new *ab initio* many-body photoemission theory to calculate the MTE of photoemitted electrons. Our results show that excited bulk electronic states and coherent electron-photon-phonon scattering, both of which the previous works ignore, play significant roles in photoemission from PbTe(111). Our work improves the understanding of fundamental processes governing photoemission and thus will help searching for next-generation high-brightness photocathode materials (MTEs ≤ 10 meV).

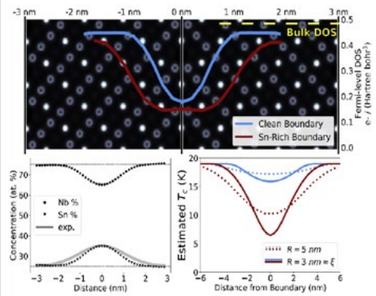
M. B. Andorf, V. A. Lebedev, and P. Piot



Advanced beam cooling techniques are being developed to address the challenge of luminosity degradation that occurs during a beam store in high brightness hadron and heavy-ion colliders. In this paper we develop formulae to compute the expected gain from a mid-IR optical amplifier and also present wave-optics simulations to compute the interaction between an amplified radiation wave-packet from the pickup undulator inside the kicker undulator. This paper quantifies the increase in damping rates that can be achieved with a Cr:ZnSe amplifier subject to the constraints imposed by the bypass chicane to be used for the IOTA demonstration.

Ab Initio Theory of the Impact from Grain Boundaries and Substitutional Defects on Superconducting Nb_3Sn

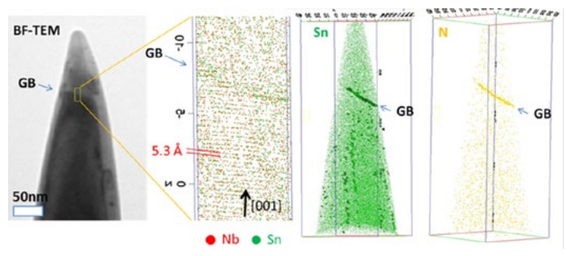
M. M. Kelley, N. S. Sitaraman, and T. A. Arias



Nb_3Sn offers the potential to significantly advance superconducting radio frequency (SRF) technology by improving the efficiency of accelerating cavities, but preserving the material's performance requires special attention to its microstructual properties. This study provides the first *ab initio* investigation to predict the impact of grain boundaries on the superconducting performance of Nb_3Sn. The results of this study will inform CBB experimentalists on how to adjust cavity baking recipes to optimize Nb_3Sn's performance.

Grain-Boundary Structure and Segregation in Nb_3Sn Coatings on Nb for High-Performance Superconducting Radiofrequency Cavity Applications

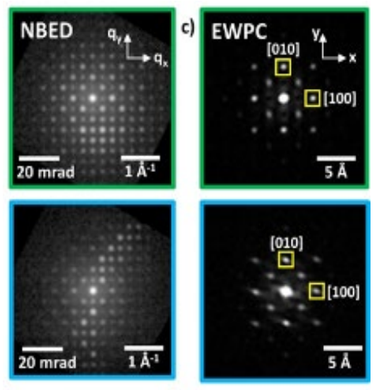
J. Lee, Z. Mao, K. He, Z. H. Sung, T. Spina, S.-I. Baik, D. L. Hall, M. Liepe, D. N. Seidman, and S. Posen



In this study we looked at Nb_3Sn grain boundaries made by Fermilab and by Cornell. We found that grain boundaries in samples from cavities that performed well have no compositional inhomogeneities within uncertainty. On the other hand, grain boundaries in samples from cavities with some performance degradation showed a small excess tin at the grain boundaries. Additional studies are planned to investigate if the excess tin could be a cause for the degradation. We also showed that this excess tin could be avoided by modification of the coating parameters.

The Exit-Wave Power-Cepstrum Transform for Scanning Nanobeam Electron Diffraction: Robust Strain Mapping at Subnanometer Resolution and Subpicometer Precision

E. Padgett, M. E. Holtz, P. Cueva, Y.-T. Shao, E. Langenberg, D. G. Schlom, and D. A. Muller



Here, we present the EWPC (exit-wave power cepstrum) transform approach for robust strain mapping at sub-nm resolution and sub-pm precision. EWPC decouples the strain information from crystal mistilts and thickness variation artifacts. It provides a mapping to a good basis for performing machine learning of structure-property relationships, without being dominated by imaging artifacts that have plagued previous approaches. This project enhances the CBB's capabilities for the SRF thrust, especially for studying the polycrystalline Nb_3Sn coatings used in the superconducting RF cavities. The EWPC method provides a robust way to study the local strain distribution in polycrystalline Nb_3Sn coatings, providing materials insights into designing better SRF cavities.

Welcome New CBB Members

We are delighted to welcome a number of new and returning members to CBB.

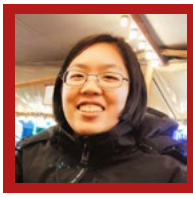
Learn more about our research projects on our CBB Research web pages by clicking on each theme.
Themes: Beam Production (PHC), Beam Acceleration (SRF), and Beam Dynamics and Control (BDC)

FACULTY

Sandra Biedron
University of New Mexico
BDC theme

GRADUATE STUDENT

Amy Zhu
Cornell University
PHC theme



GRADUATE STUDENT

Lucy Lin
Cornell University
BDC theme

GRADUATE STUDENT

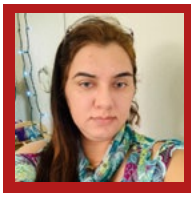
Chris Parzyck
Cornell University
PHC theme

GRADUATE STUDENT

Jason Gibson
University of Florida
PHC theme

GRADUATE STUDENT

Aiden Harbick
Brigham Young University
SRF theme

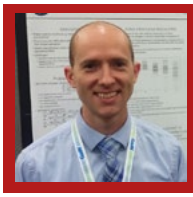


GRADUATE STUDENT

Aasma Aslam
University of New Mexico
BDC theme

GRADUATE STUDENT

Nilanjan Banerjee
Cornell University
SRF theme

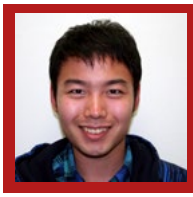


POSTDOC

Benjamin Francis
Brigham Young University
SRF theme

POSTDOC

Dulanga Somaratne
Cornell University
PHC theme



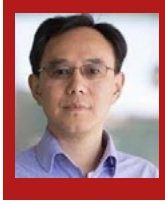
POSTDOC

Chenyu Zhang
Cornell University
BDC theme

POSTDOC

Nathan Majernik
UCLA
PHC theme

SLAC



NEW PARTNER INSTITUTION

CBB welcomes SLAC National Accelerator Laboratory. SLAC scientists (left to right) Zhirong Huang, who is also a CBB External Advisory Board member, Bruce Dunham, Auralee Edelen, and Adi Hanuka collaborate on photoinjector optimization and Machine Learning.

Summer Students - REU 2020

CBB strives to broaden the pipeline of accelerator scientists by increasing awareness of the discipline beyond the walls of national accelerator laboratories and by actively seeking out the participation of students and senior researchers from underrepresented groups. The Research Experience for Undergraduates (REU) has been a key component of this goal. Brigham Young University, University of Chicago, and Cornell University hosted CBB REU programs again this summer.

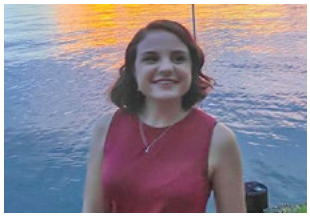
Contribute to cutting edge discovery.

Experience interdisciplinary research.

Learn alongside individuals from a wide range of nationalities, cultures, and educational backgrounds.

Explore unique areas of science.

Check out what a few REU students had to say!

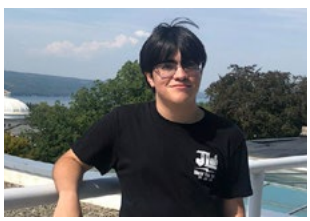


Jeanne Garriz
Louisiana State University
"This experience has taught me a lot about accelerator physics research and about the complexities of research in general. My area of research was just one tiny part of accelerator research, and most areas of research are very specialized like that. It's taught me that even the most seemingly simple tasks can be extremely complicated."
(more)

Jack Isen
UCLA
"Even though my project was largely independent, I made use of the guidance and assistance of many others. I think that this experience has shown me that all of research is collaborative to some extent and has emphasized the importance of being able to present research clearly."
(more)

Menaka Kumar
North Carolina State University
"Over the summer, I worked with Dr. Alice Galdi and Chris Pierce to investigate the effect of space charge on solenoid scan measurements in the Cornell MTE meter through particle tracking simulations in General Particle Tracer (GPT) and Python. I was able to quantify the effect of space charge on MTE measurements at various pulse lengths and voltages."
(more)

Emilie LaVoie-Ingram
Jacksonville University
"Although I am disappointed I couldn't be in Ithaca this summer, I have enjoyed making virtual friends. We all get together and talk for hours about our hobbies, engaging topics, anything! It is a nice, refreshing break after long days of research."
(more)



Pedro Rivera-Cardona
University of Puerto Rico, Mayagüez Campus
"The thing I enjoyed most about this experience was being able to interact with interns from different states, and communicating with experienced faculty about my future career goals."
(more)

Awards

Auralee Edelen named the 2020 Panofsky Fellows

Auralee Edelen (CBB Faculty at SLAC) named the 2020 Panofsky Fellow at the Department of Energy's SLAC National Accelerator Laboratory

Full Article here:

This award recognizes exceptional early-career scientists who would most benefit from the opportunity to do their research at the lab, providing generous funding for five years of research and an opportunity for continuing appointment at SLAC.

Recent Graduations

Will DeBenedetti
Ph.D. Recipient
Cornell University
Thesis: Atomic-Scale Control of TiO_2 in Air and Solution

Joshua Paul
Ph.D. Recipient
University of Florida
Thesis: Computational Discovery and Characterization of Low-Dimensional Materials

Happenings

CBB regularly hosts seminars and conferences. Stay up to date @ cbb.cornell.edu/

November 10 - 13, 2020

$Nb_3SnSRF'20$ International Workshop
Niobium-3-Tin Superconducting Radio Frequency Science, Technology, and Applications

Held virtually - Poster

CBB MISSION:

Transform the reach of electron beams by advancing fundamental knowledge and applying it to increase beam brightness x100 and reduce the cost and size of key enabling technologies. Ensure that these new approaches are realized in operating accelerators by transferring the best of them to national labs and industry. Educate and inspire a diverse generation of students to prepare them for a broad set of career paths including leadership in interdisciplinary team science.

CBB Partners

Project Areas

THEORY
New methods are suggested by theory and simulation

IMPLEMENTATION
Guided by theory, materials are grown and ideas are developed

CHARACTERIZATION
Materials are characterized to determine properties

TESTS
New methods are tested under beam conditions

APPLICATIONS
New methods are implemented in working accelerators

Convergence Research & How We're Connected

CBB's brighter beams will advance the frontiers of physics, chemistry, materials science, biology, industry, and medicine.

CBB partners work together in **project areas** from theory to application, driven by the Center's **objectives**. This convergence research benefits a wide range of accelerator **applications**.

Current projects are listed on page 7.

Objectives

BEAM PRODUCTION
Photocathodes that produce100x brighter electron beams

- High peak intensity, low MTE photocathodes
- Photocathodes for harsh conditions
- Nanostructured photoemitters

BEAM ACCELERATION
Methods for high performance superconducting RF accelerating cavities

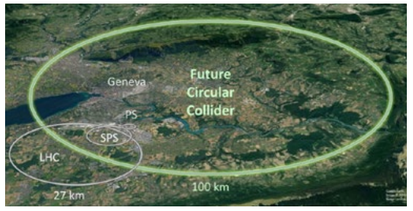
- Advanced materials for cavities
- Multilayers and inhomogeneous layers
- Demonstrations and extreme conditions

BEAM DYNAMICS AND CONTROL
Methods to conserve, cool and control beams

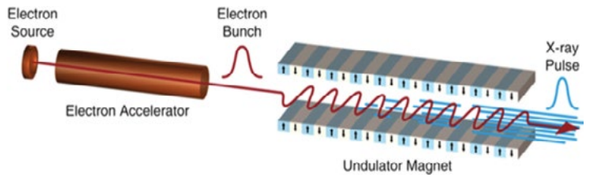
- Brightness conservation from bright sources
- New approaches to Beam Cooling
- Advanced optimization schemes

Applications

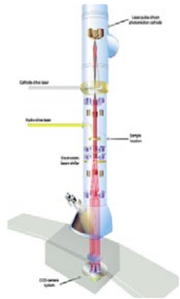
Colliders with higher luminosity and cheaper acceleration =
Expanded scientific reach



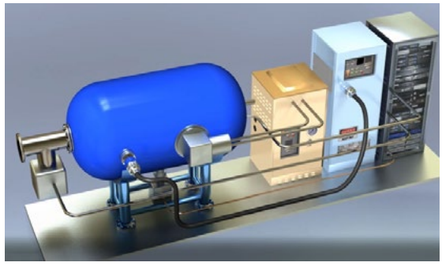
X-ray FELs with brighter electron beams =
Lower cost and/or higher energy X-rays



Electron microscopy and ultrafast electron diffraction with online tuning =
Imaging at the atomic scale with unprecedented spatial and temporal resolution



New SRF accelerators =
Innovation in the semiconductor industry, new green technologies, and a beam in every basement



CURRENT PROJECTS

Each year CBB reviews and updates its strategic plan and carefully selects projects that move it towards research objectives.

PI Name/Co-Mentors	Beam Production (PHC) Projects	Students and Post-docs
Arias / Cultrera and Karkare	*Ab initio* theory of photoemission and of photomaterials	J. Kevin Nangoi
Bazarov/ Hines and Padmore	Femtosecond Nonequilibrium Multi-photon Photoemission near the Photoemission Threshold, Improving robustness of photocathodes with various activation methods and capping techniques	Jai Kwan Bae
Bazarov / Galdi and Rosenzweig	Cryogenic photocathode characterization in a low voltage electron gun	Chris Pierce
Hennig / Karkare and Galdi	Computational synthesis of photocathodes by epitaxial growth	Jason Gibson
Hines / Galdi and Shen	Air-stable, high performance photocathodes	Amy Zhu, Jan Balajka, Dulanga Somaratne
Karkare / Padmore and Bazarov	Optical and X-ray characterization of Alkali-antimonides	Pallavi Saha
Karkare / Maxson and Padmore	3-D energy-momentum distribution measurements from single crystal metals	Chris Knill
Maxson / Musumeci and Dunham	Alkali Antimonides at High Gradients	Chad Pennington
Maxson / Hennig and Hines	Improving the structural quality of alkali antimonide photocathodes via MBE growth and advanced characterization techniques: towards epitaxy and atomically flat surfaces	Alice Galdi
Padmore / Karkare and Bazarov	Zone Plate Based Nano-emitters	Oksana Chubenko
Rosenzweig / Maxson and Huang	Optimization of ultra-compact free-electron laser performance with very low MTE photocathodes very low MTE photocathodes	Nathan Majernik, Gerard Lawler
Rosenzweig / Karkare and Filippetto	Extreme High Brightness Electron Source from Intense Laser Illumination of Nano-Blades	Joshua Mann, Gerard Lawler
Shen / Galdi and Hennig	Atomically Ordered & Engineered Materials for Photocathodes	Chris Parzyck

PI Name/Co-Mentors	Beam Acceleration (SRF) Projects	Students and Post-docs
Arias / Sethna and Posen	Nucleation of Nb_3Sn and impact of point defects on electron scattering	Nathan Sitaraman
Arias / Sethna and Sun	Nb_3Sn interfaces: importance to growth and inverse-Q behavior	Michelle Kelley
Hennig / Transtrum and Sibener	Thermodynamics and superconducting properties of novel SRF superconductors	Ajinkya Hire
Liepe / Muller and Sibener	Alternative Growth Methods of Nb_3Sn based on Electroplating and Sputtering	Zeming Sun
Liepe / Farber and Transtrum	Improving Vapor Diffusion Nb_3Sn Growth to Increasing Maximum Fields in Nb_3Sn	Ryan Porter
Liepe / Elam and Hennig	Next-Gen SRF Surfaces	Thomas Oseroff
Muller / Sun and Transtrum	M1: Nb_3Sn Composition and Strain	Zhaslan Baraissov
Sibener / Hennig and Liepe	Surface scattering studies of alloying mechanisms, diffusion and modification of interfacial forces of Sn on oxidized Nb at SRF cavity preparation temperatures and Sn coverages	Jacob Graham, Caleb Thompson
Sibener / Liepe and Arias	Growth and spatially resolved surface characterization of smooth homogeneous Nb_3Sn thin films	Rachael Farber, Sarah Willson
Sibener / Liepe and Posen	Sn Nucleation, diffusion, and Nb_3Sn Alloying mechanisms studied at the atomic scale to inform optimal Nb_3Sn growth procedures	Sarah Willson, Rachael Farber
Transtrum / Liepe and Sethna	Time-Dependent Ginzburg-Landau studies of realistic materials and surfaces	Aiden Harbick
Transtrum / Hennig and Liepe	Optimizing surface layers for SRF Performance	Ben Francis

PI Name/Co-Mentors	Beam Dynamics and Control (BDC) Projects	Students and Post-docs
Bazarov / Piot and Rubin	Optical Stochastic Cooling in CESR and development of the 400 kV electron photoemission gun diagnostics beamline for advanced beam control experiments.	Matt Andorf
Bazarov / Andorf and Piot	Interferometric studies for optical stochastic cooling and development of the 400kV electron photoemission gun diagnostics beamline for advance beam control experiments.	Samuel Levenson
Biedron / Edelen and Roussel	Intelligent laser control with uncertainty quantification for electron beam generation	Aasma Aslam
Hoffstaetter / Power and Kim	Operating hadron coolers with Machine Learning	Lucy Lin
Karkare / Huang and Musumeci	Development of the ASU-DC cryogun	Gevork Gevorkyan
Kim / Dunham and Hanuka	Extensible software tools and methods for using surrogate modeling in injector and FEL systems	Lipi Gupta
Kim / Maxson and Rosenzweig	Brightness limiting effects of point to point space charge	Matt Gordon
Kim / Hoffstaetter and Power	Large scale multi-objective Bayesian optimization for online accelerator control and tuning	Ryan Roussel
Kim / Valishev and Nagaitsev	Experimental nonlinear integrable optics studies at the integrable optics test accelerator	Nikita Kuklev
Maxson / Musumeci and Dunham	Beam Dynamics for Ultrafast Electron Diffraction with High QE cathodes: Charge Density and Laser fluence effects	William Li
Maxson / Kourkoutis and Muller	Ultrafast electron diffraction as an application demonstration of CBB photocathodes, and transmission electron microscope modeling for online optimization	Cameron Duncan
Muller / Maxson and Edelen	Microscope Tuning by ML and Emittance Optimization	Chenyu Zhang
Musumeci / Edelen and Filippetto	Machine-learning assisted high brightness photoinjector optimization	Eric Cropp
Piot / Bazarov and Rubin	Optical Transport and Beam Manipulation for Optical Stochastic Cooling	AJ Dick

Recent Publications

A. Galdi, W. J. I. DeBenedetti, J. Balajka, L. Cultrera, I. V. Bazarov, J. M. Maxson, and M. A. Hines, "The effects of oxygen-induced phase segregation on the interfacial electronic structure and quantum efficiency of Cs_3Sb photocathodes," The Journal of Chemical Physics, vol. 153, no. 14, p. 144705, Oct. 2020, doi: 10.1063/5.0024020. [Online].

A. A. McMillan, J. D. Graham, S. A. Willson, R. G. Farber, C. J. Thompson, and S. J. Sibener, "Persistence of the Nb(100) surface oxide reconstruction at elevated temperatures," Superconductor Science and Technology, vol. 33, no. 10, p. 105012, Oct. 2020, doi: 10.1088/1361-6668/abaec0. [Online].

J. Rosenzweig, N. Majernik, R. Robles, G. Andonian, O. Camacho, A. Fukasawa, A. Kogar, G. Lawler, (John) Jianwei Miao, P. Musumeci, B. Naranjo, Y. Sakai, R. Candler, B. Pound, C. Pellegrini, C. Emma, A. Halavanau, J. Hastings, Z. Li, M. Nasr, S. G. Tantawi, P. Anisimov, B. Carlsten, F. Krawczyk, E. Simakov, L. Faillace, M. Ferrario, B. Spataro, S. Karkare, J. Maxson, Y. Ma, J. S. Wurtele, A. Murokh, A. Zholents, A. Cianchi, D. Cocco, and B. Van der Geer, "An Ultra-Compact X-Ray Free-Electron Laser," New Journal of Physics, Aug. 2020, doi: 10.1088/1367-2630/abb16c. [Online].

Liepe, M, "APS -2020 Fall Meeting of the APS Division of Nuclear Physics - Event - Compact Superconducting RF Electron Accelerating Systems," in Bulletin of the American Physical Society, 2020 [Online].

M. B. Andorf, V. A. Lebedev, and P. Piot, "Single-pass Cr:ZnSe amplifier for broadband infrared undulator radiation," Optics Express, vol. 28, no. 18, p. 26601, Aug. 2020, doi: 10.1364/OE.396431. [Online].

M. B. Andorf, W. F. Bergan, I. V. Bazarov, J. M. Maxson, V. Khachatryan, D. L. Rubin, and S. T. Wang, "Optical Stochastic Cooling with an Arc-Bypass in CESR," arXiv:2007.13136 [physics], Jul. 2020 [Online].

C. M. Pierce, M. B. Andorf, E. Lu, C. Gulliford, I. V. Bazarov, J. M. Maxson, M. Gordon, Y.-K. Kim, N. P. Norvell, B. M. Dunham, and T. O. Raubenheimer, "Low intrinsic emittance in modern photoinjector brightness," Physical Review Accelerators and Beams, vol. 23, no. 7, Jul. 2020, doi: 10.1103/PhysRevAccelBeams.23.070101. [Online].

C. J. R. Duncan, D. A. Muller, and J. M. Maxson, "Lossless Monochromation for Electron Microscopy with Pulsed Photoemission Sources and Radio-Frequency Cavities," Physical Review Applied, vol. 14, no. 1, Jul. 2020, doi: 10.1103/PhysRevApplied.14.014060. [Online].

E. Padgett, M. E. Holtz, P. Cueva, Y.-T. Shao, E. Langenberg, D. G. Schlom, and D. A. Muller, "The exit-wave power-cepstrum transform for scanning nanobeam electron diffraction: robust strain mapping at subnanometer resolution and subpicometer precision," Ultramicroscopy, vol. 214, p. 112994, Jul. 2020, doi: 10.1016/j.ultramic.2020.112994. [Online].

J. K. Nangoi, S. Karkare, R. Sundararaman, H. A. Padmore, and T. A. Arias, "*Ab initio* many-body photoemission theory of transverse energy distribution of photoelectrons: PbTe(111) as a case study with experimental comparisons," arXiv:2006.11924 [cond-mat, physics:physics], Jun. 2020 [Online].

R. D. Veit, R. G. Farber, N. S. Sitaraman, T. A. Arias, and S. J. Sibener, "Suppression of nano-hydride growth on Nb(100) due to nitrogen doping," The Journal of Chemical Physics, vol. 152, no. 21, p. 214703, Jun. 2020, doi: 10.1063/5.0007042. [Online].

M. M. Kelley, N. S. Sitaraman, and T. A. Arias, "*Ab Initio* Theory of the Impact from Grain Boundaries and Substitutional Defects on Superconducting Nb_3Sn," arXiv:2005.12133 [cond-mat, physics:physics], May 2020 [Online].

J. N. Nelson, C. T. Parzyck, B. D. Faeth, J. K. Kawasaki, D. G. Schlom, and K. M. Shen, "Mott gap collapse in lightly hole-doped $Sr_{2-x}K_xIrO_4$," Nature Communications, vol. 11, no. 1, May 2020, doi: 10.1038/s41467-020-16425-z. [Online].

M. B. Andorf, V. A. Lebedev, and P. Piot, "A Single-pass Cr:ZnSe Amplifier for Broadband Infared Undulator Radiation," arXiv:2004.13223 [physics], Apr. 2020 [Online].

A. R. Pack, J. Carlson, S. Wadsworth, and M. K. Transtrum, "Vortex nucleation in superconductors within time-dependent Ginzburg-Landau theory in two and three dimensions: Role of surface defects and material inhomogeneities," Physical Review B, vol. 101, no. 14, Apr. 2020, doi: 10.1103/PhysRevB.101.144504. [Online].

J. B. Rosenzweig, "Ultra-compact X-ray FEL Based on Advanced Cryogenic RF Techniques," in Proceedings of the APS Virtual April 2020 Meeting, Virtual, 2020 [Online].

J. Lee, Z. Mao, K. He, Z. H. Sung, T. Spina, S.-I. Baik, D. L. Hall, M. Liepe, D. N. Seidman, and S. Posen, "Grain-boundary structure and segregation in Nb_3Sn coatings on Nb for high-performance superconducting radiofrequency cavity applications," Acta Materialia, vol. 188, pp. 155–165, Apr. 2020, doi: 10.1016/j.actamat.2020.01.055. [Online].