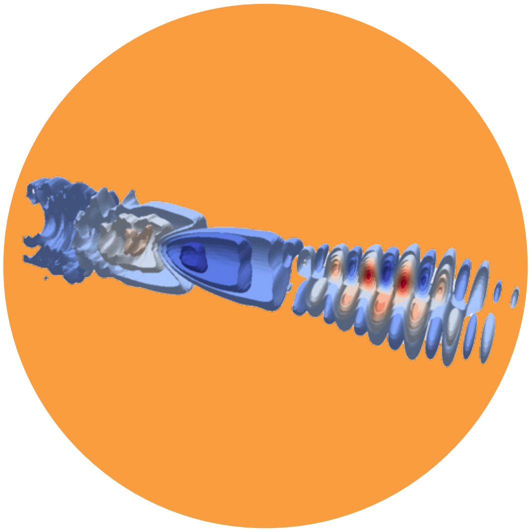

Image: Snapshot of a 3D WarpX simulation showing the longitudinal electric field of a laser-wakefield accelerator. (For more details, see article on page 34).

APS DPB NEWS

APS Division of Physics of Beams Annual Newsletter ////////// **2022**

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In Memoriam

Dear Readers,

Welcome to the 2022-2023 APS-DPB newsletter! We are excited to introduce the 19th edition, which features updates from accelerator and beam facilities including the Facility for Rare Isotope Beams (FRIB), the IsoDAR cyclotron, the Electron-Ion Collider and the Spallation Neutron Source. Additionally, this year's edition brings a particular focus on highlighting significant recent efforts in our community including the recently completed Snowmass process, outreach efforts in Africa, the Accelerator Science and Engineering Traineeship (ASET) Program, the Center for Bright Beams as well as the development of simulation tools for accelerator and beams.

In addition to these featured articles, you will also find recurring articles such as a message from Chair Frank Zimmermann, an update from IPAC and the 2022 APS DPB Awards & Fellowships, a discussion of the benefits of division activities for current and future members, our interview with the DPB Dissertation Award Recipient Ihar Lobach and notice of some important dates.

This year IPAC returned to an in-person format for the first time in two years since the pandemic started. About 850 participants from 37 countries gathered in Bangkok, Thailand for a successful conference. It was wonderful to finally meet our community after a forced lockdown period.

We would like to thank all of our authors for their valuable contributions and our 2022 APS DPB Executive Committee Members for their endless support.

As always, don't hesitate to get in touch if you would like to share your research in the next issue.

Enjoy,

Siqi Li, Ph.D.
APS DPB Newsletter Co-Editor
and Early Career Member-at-Large
SLAC National Accelerator Laboratory
siqili@slac.stanford.edu / (650) 926-3032

Marlene Turner, Ph.D.
APS DPB Newsletter Co-Editor
and Early Career Member-at-Large
Lawrence Berkeley National Laboratory
marleneturner@lbl.gov / (510) 717-9935

Meet the 2022 Executive Committee

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(01/22–12/22)
Frank Zimmermann
CERN

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(01/22–12/22)
Camille Ginsburg
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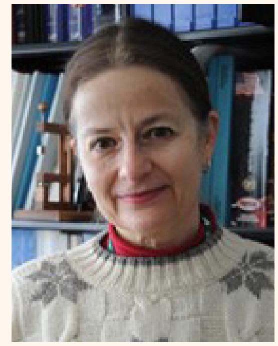
Vice-Chair/Fellowship Committee Chair
(01/22–12/22)
Mei Bai
SLAC National Accelerator Laboratory

Past Chair/Nominating Committee Chair
(01/22–12/22)
Sarah Cousineau
Oak Ridge National Laboratory



Secretary/Treasurer
(01/17–12/22)
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Argonne National Laboratory

Deputy Secretary/ Treasurer
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MIT

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(01/19–12/22)
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(01/21–12/23)
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Element Aero

Member-at-Large
(01/22–12/24)
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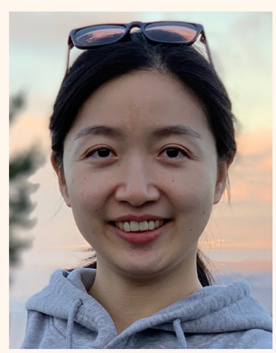
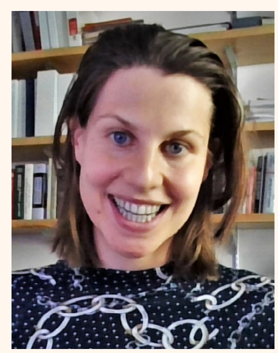
SLAC National Accelerator Laboratory



Early Career Member-at-Large
(01/21–12/22)
Siqi Li
SLAC National Accelerator Laboratory



Early Career Member-at-Large
(01/22–12/23)
Marlene Turner
Lawrence Berkeley National Laboratory

Non-Voting Members

IPAC'24 Chair
(1/20–12/22)
Fulvia Pilat
Oak Ridge National Laboratory

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(1/22–12/22)
Valeri Lebedev
JINR

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(1/22–12/22)
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Michigan State University

From the Chair

Frank Zimmermann, *European Organization for Nuclear Research (CERN)*

After two years of virtual meetings, the past year has seen the return of in-person conferences. The first of these was the APS April Meeting in New York, where the DPB's contributed sessions drew an unusually large and enthusiastic audience, mostly consisting of students and early-career members. For many of them, it was the first time to attend an in-person conference. I would like to highlight that students who are (or become) DPB members can apply for a DPB travel grant to support their attendance of the April Meeting. So far only students from a few specific universities have been making use of this opportunity. More generally, I also am hoping that in the coming years, we can maintain and further raise the attractiveness of the April Meeting DPB sessions. The 2023 April Meeting will be held in Minneapolis.

Last June, the International Particle Accelerator Conference (IPAC'22) in Bangkok was the first major in-person accelerator conference after the pandemic. About 850 accelerator experts and students attended, about 150 of whom hailed from the United States. It was a pleasure to see so many lively discussions, innovative ideas and new connections appearing all over the place and at all times, including over breakfast, coffee, lunch and dinner.

In July 2022, the DPB and the key members of the accelerator community joined the DPF and a large number of High Energy Physicists in Seattle, wrapping up the Snowmass 2021 community meeting. A major outcome of the Snowmass Accelerator Frontier discussions is the recommendation of a National Future Collider R&D Program to enable preparation for the medium- and long-term future. The proposed Collider R&D Program would complement the already existing General Accelerator R&D (GARD) program and the operating Accelerator and Test facilities. It would, in particular, allow engaging in the design, and coordinating the development of, next-generation collider projects covering three areas: (1) Addressing in an integrated fashion the technical challenges of promising future collider concepts that are not covered by the existing General Accelerator R&D (GARD) program; (2) enabling synergistic U.S. engagement in ongoing global efforts (e.g., FCC, ILC, IMCC); and (3) developing collider concepts and proposals for options feasible to be hosted in the U.S. (e.g., CCC, HELEN, Muon Collider).

Early August 2022, the NAPAC22 was held, also in person, at Albuquerque. NAPAC22, hosted by Los Alamos National Laboratory, and organized by Steve Milton and Sandra Biedron, was attended by about 450 engineers, scientists, students and industry representatives, mostly from North America. Again, it was heart-warming to witness enthusiastic live discussions of students and other early-career members. A special brown-bag luncheon discussion on sustainable accelerators attracted particular attention.

At this year's April meeting our annual DPB "Business" Meeting was held in a hybrid format, with about 15 persons attending in person, and about the same number on zoom. I would like to use this opportunity to stress that every DPB member is most warmly invited, and encouraged, to participate in the DPB Business Meetings! In February 2022, the DPB held its first "virtual community meeting" off-schedule with conferences. This meeting was well attended and a healthy discussion among attendees ensued. In view of the success and resonance, a next virtual DPB community meeting was planned for December 2022.

The Division of Physics of Beams continued its annual award programs without interruption. I would like to warmly congratulate our three new fellows, Srinivas Krishnagopal, Daniela C. Leitner and Alexei Fedotov; our dissertation award winner Ihar Lobach; and our most recent Wilson Prize Award winner Alex Dragt. They are testament to the ingenuity and talent that spans all career stages in our community. I am also pleased to recall the new Ernest Courant Outstanding Paper Recognition, jointly sponsored by the PRAB and the DPB and in honour of the late Ernest Courant (1920 - 2020), one of the founding fathers of our field. One paper published in PRAB will be recognized annually, and the recipients will be offered an invited talk on the paper at the April APS meeting. The first paper recognition was awarded to Carlo Vicaro and colleagues for their paper, "Two-color x-ray free-electron laser by photocathode laser emittance spoiler." The selection process for the next awardee is already well underway, carried out by the DPB's Publication Committee together with a designated subgroup of PRAB Editorial Board members.

Please note that student travel grant programs sponsored by the DPB have resumed, not only for the April APS meetings, but also for the US Particle Accelerator School's upcoming 2023 in-person programs (note that students must be DPB members to apply!).

Finally, some of you may still remember the year 1989, when the formation of the DPB was approved by the APS Council. Melvin Month of Brookhaven National Laboratory, Andrew M. Sessler of Lawrence Berkeley Laboratory and Martin Perl of the Stanford Linear Accelerator Center had led the drive to establish our division, which grew out of the Particle Beam Physics topical group founded a few years earlier. Now, like then, the objectives of the DPB are to advance and diffuse knowledge regarding the nature

From the Chair *(continued)*

Frank Zimmermann, *European Organization for Nuclear Research (CERN)*

of beams and the instruments used in beam research; to promote research and development in the field, including applications; and to encourage scholarly publication and education in beam science and technology.

In this context, I would like to remind you of an urgent and serious matter. The membership levels for the DPB have fallen dangerously close to the minimum division threshold for the APS. If we are not able to maintain our membership level, the DPB will no longer be eligible for division status. The APS DPB is the oldest and worldwide largest professional group in the accelerator field. Its demise would be a great loss for the accelerator community.

Therefore, please join me in reminding our community members of the importance of our professional society as a mechanism for interaction, collaboration, recognition and advocacy. Please encourage students and junior staff to join the APS DPB and to take advantage of the programs that we have recently put into place specifically for their benefit.

As last year, this newsletter is not being published in a paper format. We hope you enjoy the convenience of the online version and share in our desire to reduce cost and carbon footprint. We welcome your suggestions and feedback on the format and contents.

From the Secretary Treasurer

Marion White, *Argonne National Laboratory*

DPB continues to perform well as an APS Division. Our members are engaged, interacting with each other, sister professional societies, and with government organizations involved in accelerator-related activities. Our income is mostly derived from conferences and we have done well, but DPB membership continues to be a serious concern. If our membership is too low, DPB could lose APS Division status. Please do your best to encourage your physics colleagues who use accelerators in their research to add DPB to the APS Units to which they subscribe.

Over the past year, the DPB provided funds to support the annual newsletter, the PRAB journal, and student attendance at meetings and conferences.

The Executive Committee held four teleconferenced meetings this year. Two DPB Community Meetings were also held, one in February and one in December.

The annual election was successfully held and about a third of our membership participated. Please login to www.aps.org from time to time, verify that your email address is correctly listed, and let APS know of errors.

Finally, it has been my honor to serve as DPB Secretary/Treasurer for the past years, but the mantle will pass to William Barletta on December 31st at midnight. I have complete confidence that Bill will do an awesome job in this position!

The In-Person 2022 International Particle Accelerator Conference (IPAC'22)

Giuliano Franchetti, *GSI and Goethe University Frankfurt,* **and Frank Zimmermann,** *CERN*

The IPAC'22 APS DPB PRAB booth, manned by Frank Zimmermann (CERN, DPB Chair), Giuliano Franchetti (GSI) and Mauro Pivi (MedAustron).

Since 2020 the world had been held hostage by the COVID pandemic. During the two years 2020 and 2021, in-person conferences and workshops all but vanished. It almost seemed as if a new mode of discussing science might have replaced the traditional way of meeting altogether. Some commentators even speculated that the physics world would never return to large in-person conferences. However, the International Particle Accelerator Conference in Bangkok, hosted by the Synchrotron Light Research Institute, proved these skeptics wrong! About 850 accelerator scientists, engineers, technicians, students and industrial exhibitors from 37 countries gathered for the IPAC'22 in Bangkok, Thailand, from 12 to 17 June 2022. The APS DPB and "its" journal PRAB were represented at a special booth.

The IPAC'22 opening session stressed that many breakthroughs in combating the coronavirus pandemic had been achieved thanks to the use of particle accelerators. In particular, the molecular structure of the virus, a piece of essential information for the subsequent vaccine and drug designs, had been resolved at synchrotron radiation sources.

Although the IPAC'22 conference center was located a bit far away from downtown Bangkok, the IPAC'22 organization, chaired by Prapong Klysubun (SLRI), Hitoshi Tanaka (RIKEN) and Porntip Sudmuang (SLRI), proved excellent. COVID safety measures were well implemented. For the opening session, both covid tests from the same day and double face masks were mandatory. However, the attendees showed no fear of a massive infection outbreak. The general mood of the participants was excellent: after a forced and unpleasant lockdown, finally meeting our peers was a great relief for all, and IPAC'22, held inside the massive conference complex IMPACT at Muang Thong Thani, allowed plenty of space for discussions over breaks, coffee, lunch and dinner, and for numerous social encounters with colleagues from other institutes. These occasions fostered the generation of new ideas and offered important networking occasions, especially for students and postdocs, for many of whom this was the very first in-person conference.

Live discussions during IPAC'22.

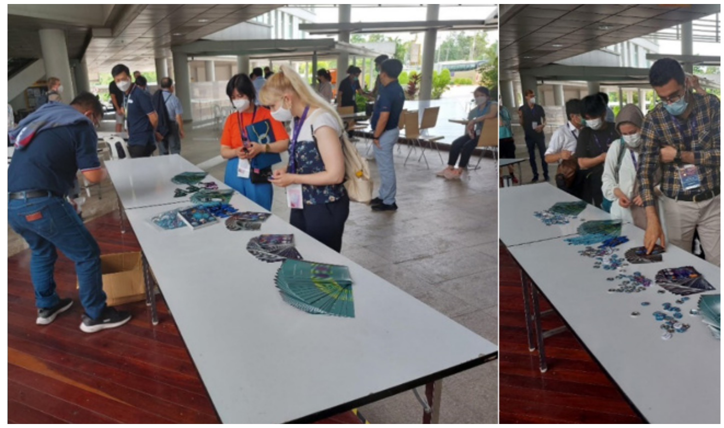
The host country Thailand assigned the highest importance to this event, and it welcomed the participants in an opening ceremony presided over by Her Royal Highness Princess Maha Chakri Sirindhorn, in presence of Professor Anek Laothamatas, the Minister of Higher Education, Science, Research and Innovation. Uncharacteristically, many IPAC'22 participants adhered to the special dress protocol issued for this occasion, thereby responding to the interest and support of the high-ranking Thai representatives with appropriate clothing! (Contrary to what one might have guessed from a viral polemical turmoil spreading weeks earlier.) Thai hospitality before, during, and after the session seemed to be extended without any limit. The welcome reception, a special evening boat cruise along the Chao Phraya River, and the Conference banquet were all enriched by traditional and modern Thai music, dances and various cultural performances.

Her Royal Highness Princess Maha Chakri Sirindhorn arriving at the IPAC’22 site.

The conference's scientific program featured a multitude of interesting talks, while the poster session area allowed for proper social distancing to comply with covid safety measures. With a few notable exceptions, such as the CEPC project leader Xinchou Lou, who delivered a fascinating in-person talk on future circular Higgs factories, our colleagues from China were mostly appearing on zoom only. Physically absent too were accelerator experts from a few US laboratories, including several invited speakers and even a prize winner. By contrast, the physical attendance from Europe and from Japan was strong: Germany even sent the largest number of IPAC’22 participants of any country. Overall, 54% of the participants hailed from Europe, 29% from Asia and 16% from the Americas. A single participant came from Africa. In total, 21% of the participants were female. Thanks to the energy and inspiring contributions of all these attendees, IPAC’22 excelled in its mission of “restarting” the particle accelerator community after the covid lockdowns, and at bringing the world closer together again.

IPAC’22 presentation highlights included details on the precise measurement of the muon anomalous magnetic dipole moment (g-2) at Fermilab, the examination at synchrotron light sources of soil samples obtained from near-Earth asteroid 162173 Ryugu by the Hayabusa2 space mission, a review of accelerator energy efficiency by PSI’s Mike Seidel, who responded to growing concerns about global warming and a discussion of the development of affordable and low-maintenance electron linacs for deployment in low- and middle-income countries by Manjit Dosanjh (Oxford U. and CERN). The latest news from ESS, LBNF/DUNE and FRIB was complemented by numerous talks and posters related to the world-record-breaking performance of SuperKEKB and to the proposed future electron-positron colliders CEPC, FCC-ee and ILC. Finally, NanoTerasu and Siam Photon Source II were two of the intriguing new photon source projects presented at IPAC’22. An industry session on accelerator technologies, hosted by Raffaella Geometrante (KYMA), offered a platform for meetings of laboratories and industry.

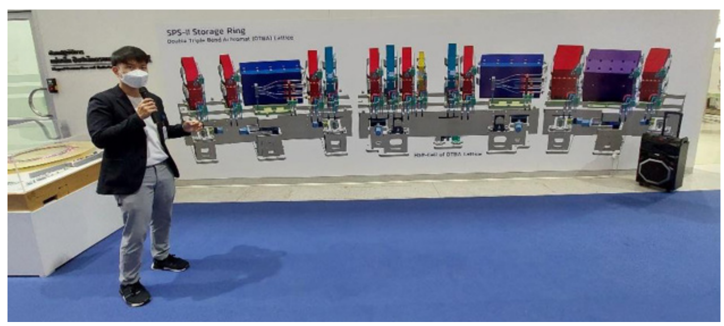
A post-conference tour brought IPAC’22 participants to the Siam Photon Laboratory. This tour showcased how the latter plays an important role in supporting Thailand, ASEAN countries



APS and Physical Review gadgets were distributed during the IPAC’22 Siam Photon Lab Tour.

and other regions with synchrotron application research. It also presented some innovative hardware prototypes for the Siam Photon Source II.

At the closing ceremony, IPAC’23 Organizing Committee Chair Ralph Assmann (DESY) announced the next venue hosting IPAC, namely the Lido di Venezia, Italy. He persuaded the participants that the 2023 conference in Italy will be as great as the one in Bangkok. Our experience at IPAC’22 has indeed been truly wonderful. The community can now look forward to the IPAC’23 meeting in Venice for a fruitful scientific exchange and a recharging through Italian history and beauty.



Explaining the accelerator lattice for the new Siam Photon Source II.

Prapong Klysubun (IPAC’22 Chair) hands over the IPAC flag to Ralph Assmann (IPAC’23 Chair).

Snowmass'21: Particle Physics and Accelerator Community Planning Exercise

Steve Gourlay *(LBNL),* **Tor Raubenheimer** *(SLAC),* **and Vladimir Shiltsev** *(FNAL);*
Snowmass'21 Accelerator Co-Conveners

This past July was an exciting time for the U.S. high energy physics community. The Snowmass Community Summer Study Workshop took place in Seattle on July 17-26 and became the culmination of the various workshops and Town Hall meetings that have taken place during 2020, 2021 and 2022 as part of Snowmass'21.

Snowmass is a particle physics community study held in the U.S. every 7-9 years (the last one was in 2013). The Snowmass'21 study (the name is historical, originally it was held in Snowmass, Colorado) is organized by the Divisions of Particles and Fields (DPF), Beam Physics (DPB), Nuclear Physics (DNP), Astrophysics (DAP) and Gravitation (DGRAV) of the American Physical Society. Snowmass'21 strives to define the most important questions for the field of particle physics and to identify promising opportunities to address them. It provides an opportunity for the entire community to come together to identify and document a scientific vision for the future of the field in the U.S. and its international partners as well. The P5 (Particle Physics Project Prioritization Panel), chaired by Hitoshi Murayama (UC Berkeley), will take the scientific input from the Snowmass'21 (final summaries published in September 2022), and by the Spring of 2023 will develop a strategic plan for U.S. particle physics that can be executed over a 10-year timescale, in the context of a 20-year global vision for the field.

Snowmass'21 activities are managed along the lines of ten "Frontiers": Energy Frontier (EF), Neutrino Physics Frontier (NF), Rare Processes and Precision Frontier (RPF), Cosmic Frontier (CF), Theory Frontier (TF), Accelerator Frontier (AF), Instrumentation Frontier (IF), Computational Frontier (CompF), Underground Facilities (UF) and Community Engagement Frontier (CEF). About 1,400 people took part in the Seattle workshop, among them some 750 in-person attendees. In general, the particle accelerator community was very well represented. More than 100 scientists and engineers from world-leading accelerator laboratories and groups were organizers of sessions and events or conveners of topical groups. In addition, numerous letters of interest (short communications) or white papers (extended input documents) have been submitted to the workshop.

For over half a century, high-energy accelerators have been a major enabling technology for particle and nuclear physics research, as well as sources of X-rays for photon science research in material science, chemistry and biology. Particle accelerators for energy and intensity frontier research in high energy physics (HEP) continuously drive the accelerator community to invent ways to increase the energy and improve the performance of accelerators, reduce their cost and make them more power efficient. Despite these past efforts, the increasing size, cost and timescale required for modern and future accelerator-based HEP projects arguably distinguish them as the most challenging scientific research endeavors. In the meantime, the international accelerator community has demonstrated imagination and creativity in developing a plethora of future accelerator ideas and proposals.

Major developments since the last Snowmass/HEPAP P5 strategic planning exercise in 2013-2014 included the start of the PIP-II proton linac; construction for the LBNF/DUNE neutrino program in the U.S.; emergence of the FCC-ee/CEPC projects for Higgs/EW physics research at CERN and in China, respectively; a significant reduction of activity related to linear collider projects (ILC in Japan and CLIC at CERN); and paradoxically, the end of the Muon Accelerator Program in the U.S. and the creation of the International Muon Collider Collaboration (IMCC) in Europe. The last decade saw several notable planning advancements, including the US DOE GARD Roadmaps, European Strategy for Particle Physics and the Accelerator R&D Roadmap, EuPRAXIA, etc.

In addition, the last Snowmass meeting took place in 2013, shortly after the confirmation of the Higgs. Goals for the Energy Frontier have changed as a result of the LHC measurements. While a Higgs/EW factory at 250 to 360 GeV is still the highest priority for the next large accelerator project, the motivation for a TeV or few TeV e+e- collider has diminished. Instead, the community is focused on a 10+ TeV (parton c.m.e.) discovery collider that would follow the Higgs/EW Factory. This is an important change that will refocus some of the accelerator R&D programs.

The technical maturity of proposed facilities ranges from shovel-ready to those that are still largely conceptual. Over 100 contributed papers have been submitted to the Accelerator Frontier of the U.S. particle physics decadal community planning exercise, Snowmass'2021. These papers cover a broad spectrum of topics: beam physics and accelerator education, accelerators for neutrinos, colliders for electroweak/Higgs studies and multi-TeV energies, accelerators for physics beyond colliders and rare processes, advanced accelerator concepts, as well as accelerator technology for radio frequency cavities (RF), magnets, targets and sources. All these papers can be found in the Snowmass'21 collection on Arxiv.org.

In 2020-2022, extensive discussions and deliberations have taken place in corresponding topical working groups of the Snowmass Accelerator Frontier (AF) and in numerous joint meetings with other Frontiers, Snowmass-wide meetings, a series of colloquium-style "Agoras," cross-Frontier forums on muon and e+e- colliders and the collider Implementation Task Force (ITF). The ITF was a special working group comprising world-wide accelerator experts to provide a comparison of the collider proposals that were submitted. A list of the AF topical groups of the ITF, as well as links to the summary papers, can be found on the Snowmass21.org website.

As co-conveners of the Snowmass'21 "Accelerator Frontier," we summarize some of the outcomes of the Snowmass process:

Future facilities: The accelerator community in the U.S. and globally has a broad array of accelerator technologies and expertise that will be needed to design and construct any of the near-term HEP accelerator projects. P5 will need to prioritize what option(s) should be developed. Planning of accelerator development and research should be aligned with the strategic planning for particle physics and should be part of the P5 prioritization process. Accelerator experts can contribute to U.S and international projects under consideration by providing top-down metrics for expected cost-scales and technology/timeline evaluations, following the ITF findings.

Among possible actively discussed future facilities options are:

- A multi-MW beam power upgrade of the Fermilab proton accelerator complex that seems to be the highest priority for the neutrino program in the 2030s. Corresponding accelerator technology and beam physics studies are needed to identify the most cost- and power-efficient solutions that could be implemented in a timely fashion leading to breakthrough results of the DUNE neutrino program;
- Several beam facilities for axion and dark matter (DM) searches are shown to have great potential for construction in the 2030s in terms of scientific output, cost and timeline, including PAR (a 1 GeV, 100 kW PIP-II accumulator ring). In general, we should efficiently utilize existing and upcoming facilities to explore dedicated or parasitic opportunities for rare process measurements — examples are the SLAC SRF electron linac, MWs of proton beam power potentially available after construction of the PIP-II SRF linac, spigots of the future multi-MW FNAL complex upgrade and at CERN, a Forward Physics Facility at the LHC, etc.;
- In the area of future colliders, several approaches are identified as both promising and potentially feasible, and so call for further exploration and support: in the Higgs/EW sector, there is growing support for the FCC-ee at CERN and proposals of somewhat more advanced linear colliders in the U.S. or elsewhere, such as C^3 and HELEN;
- At the energy frontier, the discovery machines such as *O*(10 TeV c.m.e.) muon colliders have rapidly gained significant momentum. To be in a position for making decisions on collider projects viable for construction in the 2040s and beyond at the time of the next Snowmass/P5, these concepts could be explored technically and documented in pre-CDR level reports by the end of this decade.

The U.S. HEP accelerator R&D portfolio presently contains no collider-specific scope. This creates a gap in our knowledge-base and accelerator/technology capabilities. It also limits our national aspiration for a leadership role in particle physics in that the U.S. cannot lead or even contribute to proposals for accelerator-based HEP facilities. To address the gap, the community has proposed that the U.S. establish a national integrated R&D program on future colliders in the DOE Office of High Energy Physics (OHEP) to carry-out technology R&D and accelerator design for future collider concepts. This program would aim to enable synergistic engagement in projects proposed abroad (e.g., FCC, ILC, IMCC). It would support the development of design reports on collider options by the time of the next Snowmass and P5 (2029–2030), particularly for options that can be hosted in the US, and to create R&D plans for the decade past 2030. Without such a program there may be few accelerator-based proposals for a future P5 to evaluate.

General Accelerator R&D: In addition to the above focused proposed activity, general accelerator technology development is critical and needs additional attention and support to achieve the community aspirations by the end of this decade:

- Novel high power targets should be developed to be able to accept multi-MW beams (up to 2.4 MW for the LBNF/DUNE Phase II, 4-8 MW for a future muon collider). The task requires dedicated high-power targetry R&D facilities and development of efficient high-intensity, high brightness $e+$ sources is critical for most Higgs/EW factory colliders;
- Energy-efficient SC and cold-NC RF cavities and structures need to demonstrate 70 MV/m and 70 to 150 MV/m gradients, respectively, which are needed for cost-efficient compact Higgs linear colliders. Explorations and tests of new materials with potential of sustaining higher gradients and high Q_0, as well as development of efficient RF sources are critical;
- Conceptual breakthroughs in 12-20 T high-field dipole magnets, *O*(30 T) solenoids and *O*(1000 T/s) fast-ramping magnets should demonstrate convincing proof of feasibility for high energy

proton-proton and muon colliders as well as other energy frontier collider schemes;
- Advanced wakefield accelerator concepts should strive toward demonstration of collider quality beams, efficient drivers and staging and development of self-consistent parameter sets for potential colliders based on wakefield acceleration in plasma and structures (in close coordination with international programs such as the European Roadmap, EuPRAXIA, etc.);
- Finally, in accelerator and beam physics, the focus should be on experimental, computational and theoretical studies on acceleration and control of high intensity/high brightness beams, high performance computer modeling and AI/ML approaches and design integration and optimization. The program should also include the overall energy efficiency of future facilities and re-establish a program of beam physics research on general collider-related topics towards future e+e- colliders and muon colliders.

The above items call for a substantial increase in corresponding R&D support, and should be augmented with other measures to make the US competitive in education and attraction of accelerator talent, such as:

- Strengthening and expansion of education and training programs, enhancement of recruiting (especially international talent), promotion of the field (e.g., via colloquia at universities);
- Creating an undergraduate level recruiting program structured to draw in women and underrepresented minorities (URM) that could be coordinated with the USPAS, and corresponding efforts at all career stages to support, include and retain them in the field;
- Strengthen and expand capabilities of the US accelerator beam test facilities to maintain their competitiveness with respect to worldwide capabilities.

A comprehensive summary of the Snowmass'21 report is at https://arxiv.org/abs/2301.06581

A comprehensive summary of the "Accelerator Frontier" report is available at https://arxiv.org/abs/2209.14136

FRIB Commissioning and Early Operations

Jie Wei, *Michigan State University*

In 2008, Michigan State University was selected to establish the Facility for Rare Isotope Beams (FRIB). In August 2013, the U.S. Department of Energy's Office of Science (DOE-SC) approved the FRIB project baseline with a total project cost of \$730M, with \$635.5M provided by DOE and \$94.5M provided by Michigan State University (MSU)[1]. After several years of R&D and preparation, technical construction started in 2014. The FRIB project was completed in April 2022, on budget and ahead of the baseline schedule. On May 2 2022, a ribbon-cutting ceremony marked the start of FRIB's scientific mission (Fig. 1). Major project milestones are listed in Table 1.

Because of the large project scope (Fig. 2), 8-year technical construction schedule, and state-of-the-art performance goals, a phased beam commissioning strategy was developed. Table 2 summarizes the seven beam commissioning runs, each lasting for up to two weeks, with specific strategic goals[2]. Beam commissioning started in 2017 with upstream normal-conducting devices. Driver linac commissioning was completed in April 2021 with acceleration of heavy ions the design energy using 324 superconducting radio-frequency resonators housed in 46 cryomodules operating at 2 K and 4 K with liquid-helium cooling (Fig. 3)[3]. In preparation for high-power operations, a liquid lithium charge stripper was used to strip the primary beams (Fig. 4)[4], and multiple charge states were accelerated simultaneously[5]. The target and fragment separator commissioning was completed in January 2022, with rare isotope (RIs) produced and identified[2]. The first three scientific user experiments were conducted May-August 2022.

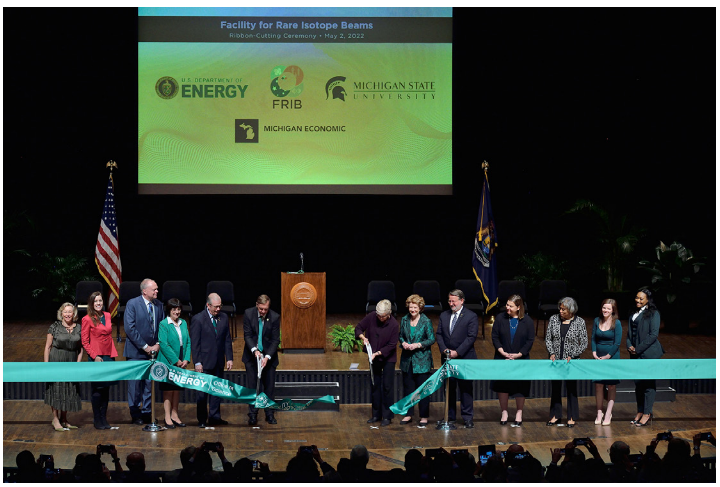


Figure 1. U.S. Secretary of Energy J. M. Granholm (center right) and MSU President S. L. Stanley Jr., M.D. (center left) cut the ribbon on May 2, 2022 to officially mark the start of FRIB's scientific mission.

Milestone	Date
Project site selection	Dec 2008
DOE & MSU cooperative agreement	Jun 2009
CD-1: alternative selection & cost range	Sep 2010
CD-2: performance baseline	Aug 2013
CD-3a: start of civil construction & long lead procurements	Aug 2013
CD-3b: start of technical construction	Aug 2014
Achievement of project Key Performance Parameters	Dec 2021
CD-4: project completion	Apr 2022
Start of scientific user experiments	May 2022

Table 1. FRIB project milestones including the critical decisions (CD-1 to CD-4).

Commissioning of the Driver Linac was done in five runs (Table 2). Run 1 commissioned the Front End (FE): the normal-conducting (NC) ion source, radio-frequency quadrupole (RFQ) and associated infrastructure. In 2018, the helium refrigeration plant (Fig. 3a) started operation[6], and Run 2 accelerated Ar and Kr beams to 2 MeV/nucleon (MeV/u) through the first three superconducting radio-frequency (SRF) cryomodules, each containing four β = 0.041 quarter-wave resonators (QWRs) and two superconducting (SC) solenoids. Run 3 and Run 4 were completed in the next two years, each raising the beam energy by another order of magnitude, to 20 MeV/u and then to 200 MeV/u. In Run 3, fifteen cryomodules were used, containing a total of 104 QWRs (β = 0.041, 0.085) and 39 SC solenoids, all at 4.5 K. At that time, FRIB became the world's highest-energy CW hadron linac. In Run 4, half-wave resonators (HWRs, β = 0.29, 0.53) at 2 K (Fig. 3b) were used to further accelerate the beam through both LS1 and LS2 (Fig. 3c). In April 2021, Run 5 concluded linac commissioning with acceleration of ions to >200 MeV/u.

After linac beam commissioning, two more commissioning runs were conducted for downstream systems. In Run 6, beam was delivered to an RI production target, with the primary beam stopped in a downstream beam dump (Fig. 5a) after the first separator dipole. Detectors were installed at the focal plane of the pre-separator for identification of rare isotopes. In Run 7, the primary beam was transported through the whole fragment separator complex (Fig. 5b).

Identification of $^{84}Se^{34+}$ marked the delivery of the last of the FRIB "key performance parameters":

- Accelerate ^{36}Ar to > 200 MeV/u with a beam current > 20 particle nA: attained March 2020;

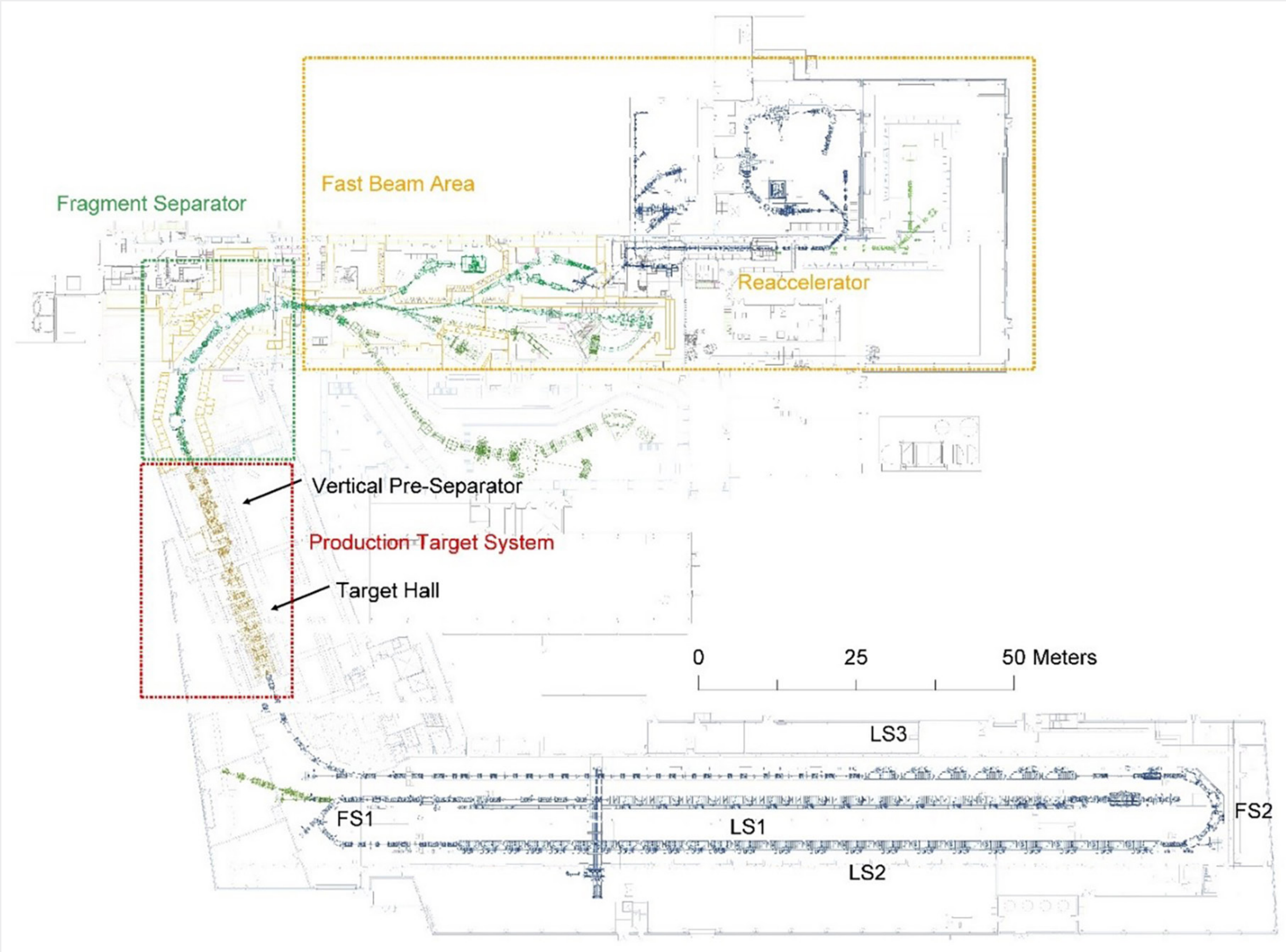


Figure 2. Layout of the FRIB facility. The underground driver linac consists of three straight segments, Linac Segment 1 through Linac Segment 3 (LS1, LS2, LS3), and two folding segments (FS1, FS2), with charge stripping in FS1. The beam delivery system (BDS) delivers the beam to the Target Hall at the linac elevation. The vertical pre-separator takes isotope beams to the ground level for transport through the fragment separator to the experimental areas.

Run	Area with beam	Beam energy (MeV/u); species	Date	Main goals
1	Front end	0.5; Ar, Kr	Jul 2017	Front end and civil integration
2	+ 3 cryomodules	~2; Ar, Kr	May 2018	Cryogenic integration
3	FE + LS1 + FS1	~20; Ar, Kr, Xe, U	Feb 2019	QWR and charge stripping validation
4	+ FS1 + LS2	~200; Ar, Kr, Xe	Mar 2020	2 K cryogenics and HWR validation
5	+ FS2 + LS3 + BDS	~200; Ar, Kr, Xe	Apr 2021	Driver linac validation
6	+ target & beam dump	RI (Se, etc.)	Dec 2021	Targetry and RI production demonstration
7	+ fragment separator	~200; Ar, Kr	Jan 2022	Readiness for user operations

Table 2. FRIB project beam commissioning stages.

- Produce and identify ^{84}Se isotopes (Fig. 6): attained December 2021;
- Measure reaccelerated RI beam energy > 3 MeV/u: attained September 2015.

With the completion of commissioning Run 7, the full technical scope of the FRIB baseline was demonstrated.

The first FRIB Program Advisory Committee approved 34 scientific experiments with nine different primary ion beams starting in 2022. Under the Run 7 operational safety envelope, primary beams of up to 1 kW were accelerated, striking a beryllium or carbon target to produce rare isotope beams for fragment separation and transportation to user stations. In parallel, the FRIB

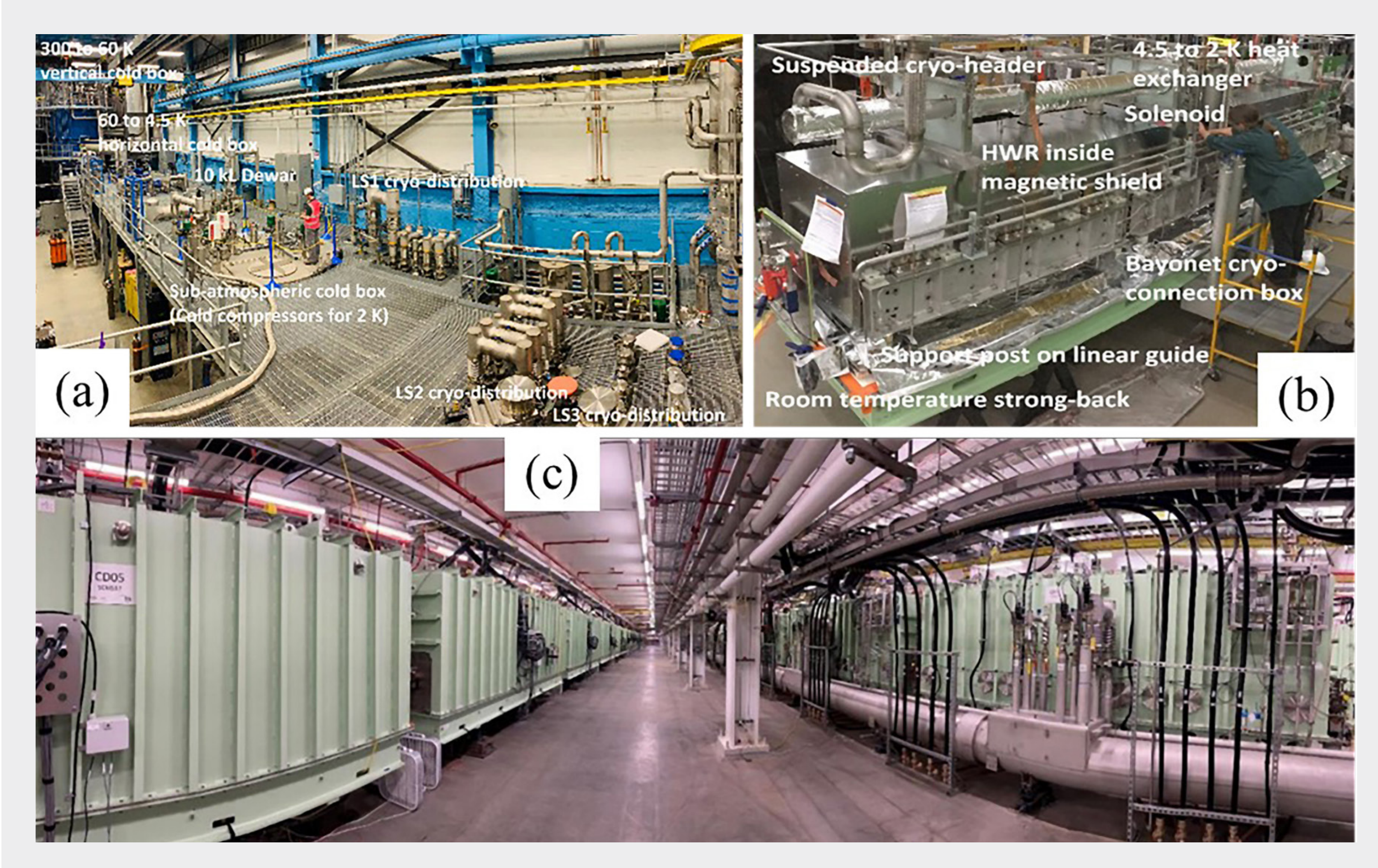


Figure 3. (a) FRIB helium refrigeration plant. (b) Partially-assembled FRIB β = 0.53 cryomodule. (c) FRIB driver linac tunnel, about 10 m underground (left: LS2; right: LS1).

industrial user program started in 2021 with the commissioning of the FRIB Single Event Effects (FSEE) beam line at the end of LS1 in the linac tunnel (Fig. 7). Beams of ^{16}O, ^{40}Ar, ^{129}Xe or ^{209}Bi were accelerated to energies of up to 40 MeV/u for FSEE users.

Fourteen years after the site selection in 2008, the FRIB baseline was delivered on cost and five months ahead of schedule (Table 2). Valuable lessons from FRIB technical design, construction, commissioning and early operations include:

- Recruit worldwide and retain key subject matter experts (own the best people);
- Develop and mature key technologies in time to support the project schedule (own the technology);
- Align interests for infrastructure investment to support key construction steps and future research (align interests, invest in infrastructure);
- Closely collaborate with U.S. national labs and world-wide partners for knowledge transfer and project support; rigorously manage collaboration (collaborate without losing control);
- Strategically facilitate phased commissioning to stagger the work force, validate design principles, feedback on improvements, and meet the schedule (phase the scope for optimization);
- Conduct rigorous external reviews, inviting the best experts to critique the work (review rigorously);
- Engage with industrial providers via exchange visits, weekly meetings and extended stays (intimately engage vendors);
- The original “turn-key” approach to procure the large-scale cryogenic helium system from industry exposed the project to serious risks in budget and scope (avoid “turn-key” on large-scale cryogenics);
- Early shortcuts taken in SRF/QWR sub-component validation were costly (avoid shortcuts);
- Shared vacuum vessels in the target area complicate maintenance (consider maintenance);
- Lack of diagnostics and correctors in the 3D geometric layout complicates fragment separation (ensure adequate diagnostics and adjustments);
- Conduct systematic R&D for novel technology — e.g. bottom-up cryomodule (systematic R&D);
- Thorough testing is needed for all major technical equipment, e.g. SRF sub-components, cryomodules, superconducting magnets (test thoroughly);
- Pro-actively facilitate critical system validation, e.g. for liquid Li stripper (facilitate critical validation).

FRIB will operate as a scientific user facility with the imperative of safe operation, guided by five paradigms: (a) Operate with >

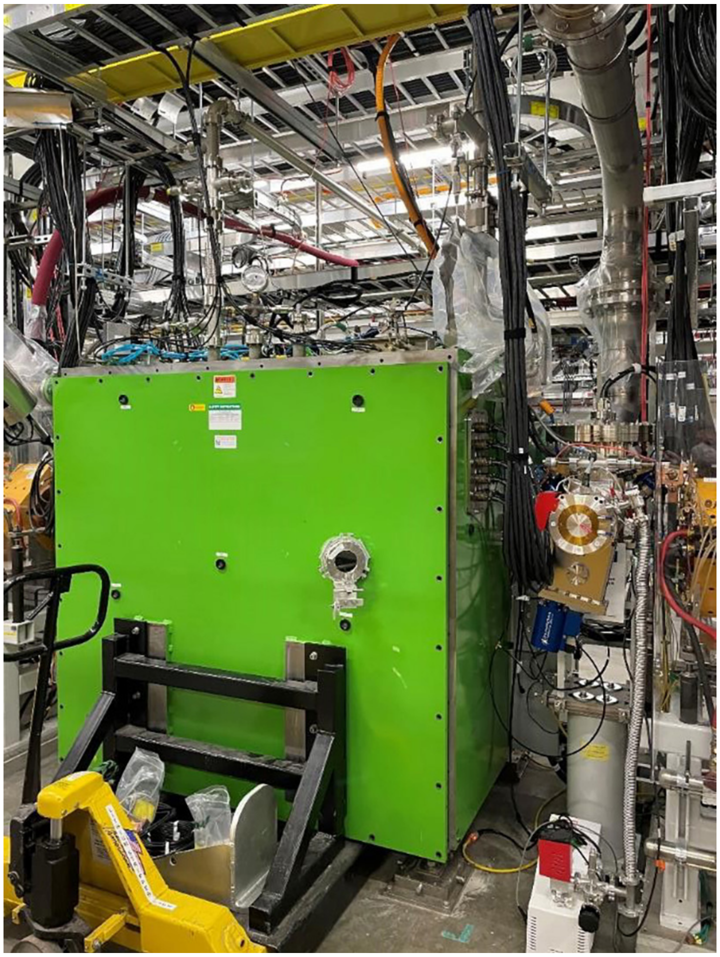


Figure 4. The liquid lithium charge stripper (left) and carbon charge stripper (right) in FS1. The green box is a secondary containment vessel enclosing the entire Li loop.

85% availability for user satisfaction; (b) ramp up the beam power to enhance discovery opportunities; (c) automate to increase the machine time available for science; (d) foster an engaged user community; and (e) deliver opportunities for all areas of science enabled by FRIB. In subsequent years, the primary beam power will be progressively increased as operational experience is accumulated, aiming for 400 kW in 2028 (Fig. 8[4]).

Accelerator improvement projects will play an essential role in updating aged systems in the laboratory that predate the FRIB project and maximizing the productivity of the facility. Work is also proceeding in preparation for future upgrades, including a doubling of the primary beam energy to 400 MeV/u to enhance the scientific reach of the facility.

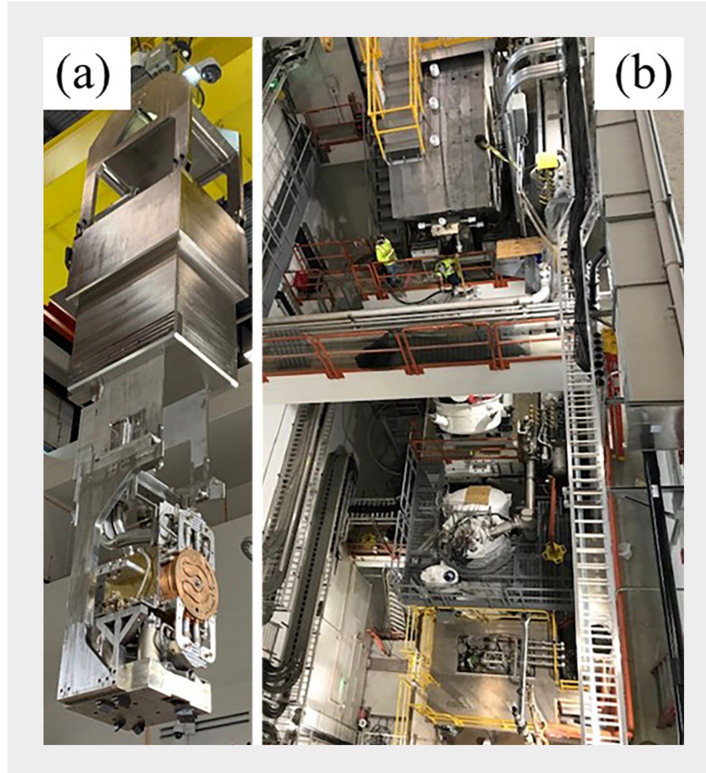


Figure 5. (a) Production target assembly before installation. (b) Vertical pre-separator area

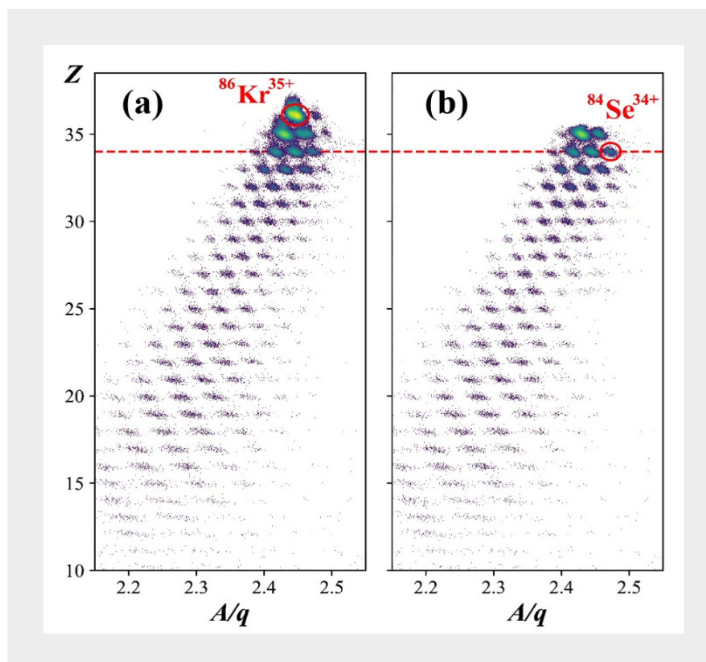


Figure 6. Particle identification for nuclei produced by a $^{86}Kr^{35+}$ beam in a 3.3 mm-thick Be target with selection by upstream magnets: (a) without charge state selection; red circle: charge state +35 of the primary beam, the most intense.

Figure 7. FSEE beam line in the linac tunnel.

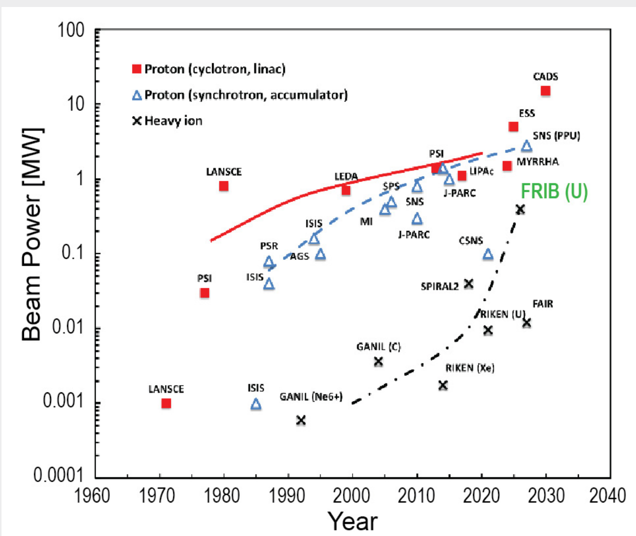


Figure 8. Beam power on target as a function of time for existing and planned power-frontier accelerator facilities.

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The IsoDAR Cyclotron and Neutrino Production Target

Daniel Winklehner, *Massachusetts Institute of Technology for the IsoDAR Collaboration*

Introduction

What do neutrinos, dark matter, medical imaging, cancer therapy and material testing for fusion have in common? They can all benefit from a very high current, cw proton beam from a compact cyclotron like the IsoDAR collaboration's HCHC-XX (High Current H_2+ Cyclotron) design[1,2]. Here, XX stands for any desired final energy from 2 MeV/amu to 60 MeV/amu. For the IsoDAR (Isotope Decay-At-Rest) experiment[3,4], we will place such a driver with 60 MeV/amu underground at the Yemilab facility in Korea. We will accelerate 5 mA of molecular hydrogen ions (H_2+) to 60 MeV/amu and strip them of their binding electrons after extraction from the accelerator. The resulting 10 mA proton beam will go to a high-power target and impinge on beryllium. The spallation neutrons from this reaction will capture on a surrounding isotopically pure ^{7}Li sleeve and produce ^{8}Li, which beta-decays, yielding a well-understood source of electron-antineutrinos (ν_e) that can be used to measure ν_e disappearance through standard and non-standard (possibly involving one or more new particles) neutrino oscillations.

This is a discovery-level experiment covering a major portion of the currently allowed parameter space for new neutrinos with >5σ sensitivity in 5 years of running. IsoDAR@Yemilab has many other compelling physics goals, among them measurements of the weak mixing angle and searching for Non-Standard Interactions (NSIs) using 7000 low-Q ν_e-e−elastic scattering events collected in five years of running, and a search for Axion-Like Particles (ALPs) [5,6]. Two enabling factors are the improved cyclotron design (using the RFQ-Direct Injection Procedure (RFQ-DIP), choice of H_2+ ion, and space-charge-driven beam dynamics), and high-power target, featuring nested beryllium shells cooled with heavy water. We will describe both in more detail later.

Due to its high current, modular design, and unique choice of ion, the HCHC-XX family of cyclotrons has applications in the production of medical isotopes for therapy and diagnostics, and in material testing for future fusion devices. As we pointed out recently[7,8], we can deliver beam to several target stations by stripping away the electron of only a portion of the H_2+ ions and subsequently separate the two species in a dipole magnet. A total of 10 mA of protons on target could increase the world production of ^{225}Ac (an alpha emitter and a highly effective therapeutic isotope) by orders of magnitude, if high power thorium targets can be built. [8] Positron Emission Tomography (PET) is another application of the medical isotopes that can be produced with our beam (e.g., ^{18}F using a HCHC-15). Finally, an array of HCHC-35 machines could be used in a neutron factory for irradiation tests of first-wall and other fusion-related materials.

The HCHC-60 driver

The main challenge with increasing the beam current in cyclotrons is space charge (an electric field pushing the particles away from each other). It leads to beam growth, halo formation, and, ultimately, losses during injection and extraction. At 60 MeV/amu, the losses during the extraction process may not exceed 200 W when occasional hands-on maintenance is required. Otherwise, the radioactive activation of the machine would be too high. This limit was empirically determined at PSI for the operation of their Injector II cyclotron. To achieve this relative particle loss of 10^{-4}, very clean beam extraction is needed and can be achieved by maximizing inter-turn separation of beam paths and minimizing beam halo (particles that potentially reside between turns). To maximize inter-turn separation, the four double-gap RF cavities can provide an energy gain per turn of almost 2 MeV in the final turn. In addition, a precessional resonance from the fall-off of the magnetic field increases turn separation locally at the position of the electrostatic extraction system comprising a thin, grounded

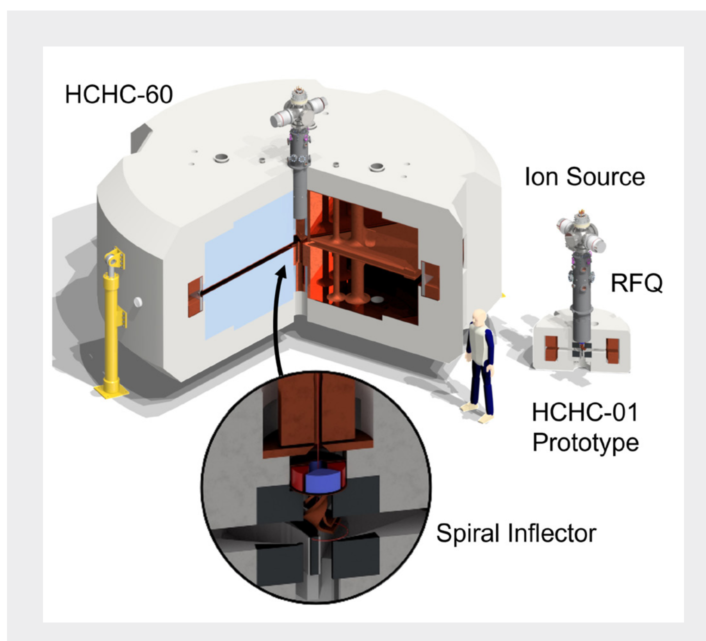

Figure 1. Examples of an HCHC-60 and an HCHC-01. The H_2+ is produced in the ion source with 80% purity, pre-accelerated and bunched in the RFQ, and guided into the cyclotron through a spiral inflector with electrostatic transverse focusing.

septum inserted between turn N-1 and N, and a negative electrode pulling the beam outwards. These are traditional ways of improving the performance of the cyclotron. In addition, the HCHC-XX design features acceleration of H_2+ instead of protons to slightly reduce space charge overall, direct axial injection through an RFQ (Radio-Frequency Quadrupole) to efficiently bunch the beam before guiding it on the cyclotron's median plane through a so-called *spiral inflector* and the utilization of a collective effect inside the bunch, aptly dubbed *vortex motion*.

Due to their higher magnetic rigidity, H_2+ ions require a larger machine, but this offers the benefit of stripping the binding electron to transform a 5 mA, 60 MeV/amu H_2+ beam into a 10 mA, 60 MeV proton beam. In addition, by virtue of this stripping mechanism (typically facilitated through a thin carbon foil), the beam can be split piecemeal into sub-beamlets delivered to several target stations. In addition, the septum could be protected by a narrow foil, transforming ions that would otherwise hit it from H_2+ to protons, which, owing to their lower magnetic rigidity, can be guided away from the septum and into a dedicated beam dump instead.

To efficiently bunch the beam and reduce the required current from the ion source, we use a short RFQ embedded in the cyclotron yoke. This RFQ is of the *split-coaxial* type, allowing it to have a small diameter despite its low resonant frequency of 32.8 MHz (corresponding to the cyclotron RF frequency). It is only 1.25 m long and accelerates to a modest 70 keV. Because the highly bunched ions quickly begin to spread (partly due to their high space charge) in both the transverse and longitudinal directions, the RFQ exit is brought as close to the median plane as possible to begin the acceleration process in the cyclotron and utilize the strong focusing of the Azimuthally Varying Field (AVF). Nevertheless, transverse refocusing using an electrostatic quadrupole device is needed before the ions can enter the spiral inflector.

Once inside the cyclotron, the bunches experience the external force of the cyclotron magnetic field and the internal force from space charge. The combination of these two forces leads to longitudinal-radial coupling, and – if the beam current, bunch size and external fields are matched – a tornado-like motion in the bunch rest-frame that forms a stable vortex with length and width of the bunch being approximately equal. This effect was first observed in PSI Injector II and subsequently reproduced in high-fidelity Particle-In-Cell (PIC) simulations using OPAL.[9,10] For the HCHC-XX design, we have optimized the cyclotron and injected beam using the OPAL code and placed collimators in the first four turns of the cyclotron to remove particles (halo) that form while the vortex is established. This leads to beam loss of 30% in the central region.[1] This beam loss does not lead to activation, as the particle energy is still below 1.5 MeV/amu. Combined with the RFQ transmission, the total beam loss from ion source to 60 MeV/amu is only about 40% in the HCHC-XX design. Using the high-fidelity OPAL simulations, we can show that the beam loss in the extraction region is around 100 W, a factor two below the safety limit.

Because almost all novel accelerator concepts are contained upstream of 2 MeV/amu, the design can easily be adapted to any final energy between 2 and 60 MeV/amu, making it a versatile *family of cyclotrons* usable in various fields of science and industry.

The high-power neutrino target

For the IsoDAR neutrino experiment, we will use an HCHC-60 to deliver 10 mA of 60 MeV protons to the target to produce ν_e with an energy spectrum peaking around 6 MeV and an endpoint of about 13 MeV. This constitutes a continuous beam power of 600 kW, which poses cooling and structural mechanics challenges. We have addressed these challenges through a design that comprises several concentric shells of beryllium, behind and between which heavy water flows at a rate of 0.031 m^3/sec (see Figure 2).

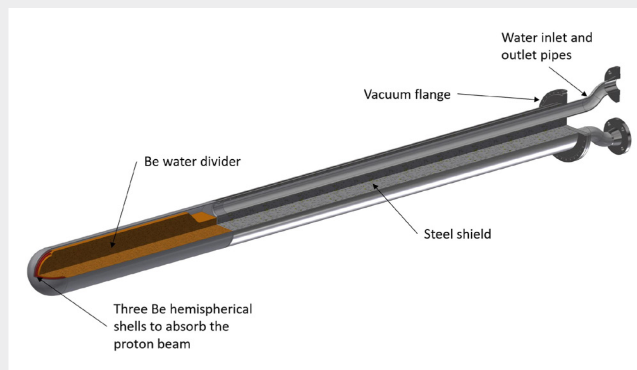

Figure 2. Torpedo with concentric beryllium shells and cooling channels.

The beam is spread out across the front surface to have a final diameter of about 20 cm. Details of the mechanical design were recently published[4], and figures and results are taken from there. The shells form the head of the so-called *torpedo*, a cylindrical structure containing the target hit by the beam (the shells), as well as the cooling mechanism. At the end of its lifetime (order of years), the torpedo can be removed and replaced from the downstream side. Due to the high activation of the torpedo, we envision remote handling using a robot. Surrounding the torpedo is a pressure vessel, the sleeve, containing a mixture of beryllium and highly isotopically pure ^{7}Li. A 15° model of the pressure vessel is shown in Figure 3 (left). The whole assembly is surrounded by steel and concrete shielding.

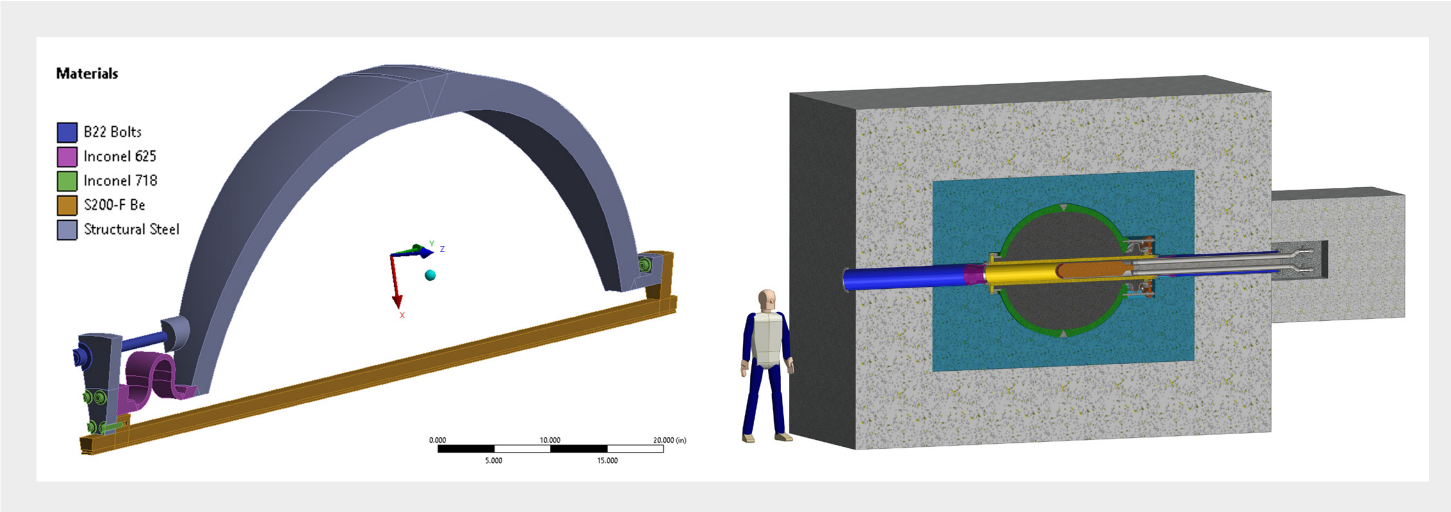

Figure 3. **Left:** 15° wedge model of the Be/Li pressure vessel. **Right:** IsoDAR target with beam pipe (blue, yellow), torpedo (orange), pressure vessel (green) and shielding (turquoise and grey).

Finite Elements Analysis (FEA) and Computational Fluid Dynamics (CFD) calculations of this structure show that the temperature and stresses are safely below the limits of materials involved.

We also performed a long-running Geant4 Monte Carlo study to optimize the Li-Be mixture and sleeve shape to maximize the neutrinos generated per proton, and another study for the shielding to minimize the number of neutrons escaping from the target, both for background reduction in the detector and for minimizing activation of the surrounding rock.

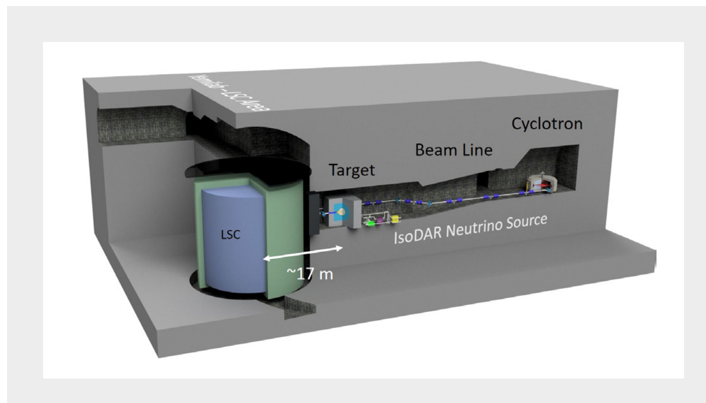

Figure 4. IsoDAR placement at Yemilab. The LSC detector is shown in blue and green.

Status and outlook

The HCHC-XX design is in a mature state, with highly accurate PIC simulations demonstrating the feasibility of the design and its novelties. Our prototype ion source (MIST-1) delivers 80% pure H_2+ beams (with H_3+ and protons the contaminants). We are upgrading the ion source with a new extraction system to increase the total beam current available. The RFQ design is finalized, and we have subcontracted a company to build the device. Beam tests scheduled for summer 2023 will demonstrate the RFQ operation and the injection into a test magnet through a spiral inflector. The next steps for the HCHC-XX are building a 1.5 MeV/amu test cyclotron to verify the establishment of a stable vortex, and then the full technical design of the HCHC-60.

The target design is also mature and we are building a small-scale prototype for injecting the Be/Li mixture under high pressure at the University of Michigan.

In the meantime, we are working with the Institute of Basic Science in South Korea on integrating IsoDAR with the Yemilab facility (see Figure 4) and the planned Liquid Scintillator Counter (LSC). We have preliminary approval to run at Yemilab, where in 2022 a cavern was excavated specifically for the IsoDAR HCHC-60.

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Upcoming Events

Conferences & Meetings

2023		
March 6–10, 2023	APS March Meeting 2023	Las Vegas, Nevada
March 20–22, 2023	APS March Meeting 2023	Virtual
April 15–18, 2023	APS April Meeting 2023	Minneapolis, Minnesota
April 24–26, 2023	APS April Meeting 2023	Virtual
May 7–12, 2023	IPAC 2023 / International Particle Accelerator Conference	Venice, Italy
September 10–15, 2023	IBIC 2022 / International Beam Instrumentation Conference	Saskatoon, Saskatchewan, Canada
June 25–30, 2023	SRF 2023 / 21st International Conference on Radio-Frequency Superconductivity	Grand Rapids, Michigan
August 27 – September 1, 2023	FLS 2023 / 67th ICFA Advanced Beam Dynamics Workshop on Future Light Sources	Lucerne, Switzerland
October 9–13, 2023	ICALEPS 23 / The 19th Biennial International Conference on Accelerator and Large Experimental Physics Control Systems	Cape Town, South Africa
October 9–13, 2023	The 68th ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams	Geneva, Switzerland

Accelerator Schools

2023		
January 23 – February 3, 2023	U.S. Particle Accelerator School (USPAS) Winter 2023	Houston, Texas
June 5–16, 2023	U.S. Particle Accelerator School (USPAS) Summer 2023	Melville, New York
June 18 – July 1, 2023	CAS RF for Accelerators	Berlin, Germany
September 25 – October 8, 2023	CAS Introduction to Accelerator Physics	Santa Susanna, Spain
November 19 – December 2, 2023	CAS Normal- and Superconducting Magnets	Sankt Pölten, Austria

Advanced Light Sources: A 24-Page Brochure Designed To Reach a Broad General Audience In Africa

Ernest Malamud, *Scientist Emeritus, Fermilab and Adjunct Professor, University of Nevada, Reno*

This article describes the creation of the brochure and the editing and production techniques that resulted in a successful product.

The physics community is expanding and new research infrastructures like light sources are emerging.

In the quest of building capacity in Africa, education and scientific cases are essential synergies to reach a new paradigm.

Several collective initiatives can enhance such a journey towards knowledge and solving societal challenge.

Twelve years ago, the first African School of Fundamental Physics and Applications was initiated in South Africa: ASP2010. Despite the pandemic and environmental crisis, the seventh edition of the ASP returns to SA, at the Nelson Mandela University in Gqberha, to train the next generation of scientists for the Africa Light Source.

Engaging with students and public to contribute to African development is also one of the purposes of the so-called LAAAMP (Lightsources for Africa, the Americas, Asia, the Middle East and Pacific). The brochure, "Advanced Light Sources and Crystallography, Tools of Discovery and Innovation," supports those developing communities.

—Christine Darve

Introduction

There are five files, in five different languages, all archived on the International Union of Crystallography web page, IUCr.org. Each file is 24 pages (A4 format), about 5 MB in pdf. With appropriate clicks you can download/view/print each of them.

- Advanced Light Sources and Crystallography: Tools of Discovery and Innovation (original and English version)
- Fuentes de Luz Avanzadas (Spanish version)
- Fontes de Luz Avançadas (Portuguese version),
- Sources lumineuses avancées (French version)
- ضوء المتقدِّمة وعلم البلورات (Arabic version)

History

In 2017 the International Science Council issued a call for proposals. The grants were for 300,000 €, "seed" grants for starting new initiatives. A group of stakeholders wrote a proposal; I did much of the writing. Our proposal was referred to at the time as LAAMP (later LAAAMP): Lightsources for Africa, the Americas, Asia, the Middle East and Pacific.

We wrote a proposal with five major tasks. The third task in the list was "publish an information brochure that describes AdLSs, Crystallography, and the many fields that they impact."

There was a competition. Our group obtained one of the first three granted in the new program.

Editing Procedures

The first steps were to create a table of contents (ToC) and define our target audiences. These crucial steps defined the brochure length and influenced planning the distribution.

I focused on Africa and aimed at a literate public: professors, students, post-docs and members of granting agencies in each country. We would be reaching out to academia in African universities, but not those with experience in building light sources. Early in the editing process, we assumed that the light source was an electron storage ring and not a FEL. The ToC was iterated in numerous emails with stakeholders. These initial crucial steps defined the brochure length.

We finally converged on 24 pages (including covers). The inside front cover served as the ToC page. That length and the ToC defined the technical level of our audience.

I have observed during many years as an APS member, serving in various offices, that many APS units produce a brochure. Many are quite attractive and clearly represent much work, but in my opinion many are too long to be widely read and end up on scientists' bookshelves.

The grant proposals required two international science unions as primary sponsors. Ours was sponsored by IUPAP, the International Union for Pure and Applied Physics and IUCr, the International Union for Crystallography. To this we added a number of relevant secondary sponsors.

I had edited a previous brochure, "Accelerators and Beams" (A&B). It went through four different editions and was distributed widely, mainly through the U.S. national labs. The fourth edition was printed in March, 2013. An estimated total of 30,000 copies were distributed. I had been the editor of A&B over the years and it was an excellent "template" for doing the new brochure "Advanced Light Sources" (ALS.)

As an aside to this article, A&B is now out of date and would benefit from an update and fresh distribution. I have volunteered to the APS Division of Physics of Beams (DPB) to take on this task.

Back to brochure history. For both brochures, A&B and ALS, I followed formal procurement procedures, learned from many years at Fermilab: define the scope of work, then make a bidders list, award the job — not necessarily to the low bidder. I applied this methodology to all aspects of the work, including the cover design and the designer to do the page layout following an initial layout I made using Microsoft Publisher. But there were important differences. A&B was designed and printed in the US and financed by DPB. ALS was produced in France and financed by the International Science Council (ISC).

There is another important aspect to the ALS brochure history. On the earlier brochure I edited, A&B, IAEA — the International Atomic Energy Agency — located in Vienna, commented to me that they had planned to edit and publish a brochure on accelerators, but that the one I had done, A&B, for APS, was so well done that they decided not to develop one themselves. This established a friendly and productive relationship with IAEA, so after finishing the ALS brochure I asked them if they could do the French translation and donate the effort. They agreed and that led to subsequent translations into Spanish, Portuguese and Arabic. The Spanish version was useful to support the effort to build a light source in Mexico whereas the other four versions were aimed primarily at African audiences.

As in both A&B and ALS, the emphasis in the ToC is application.

Other languages—Italian, German, Turkish—were proposed at various times by various people. I decided not to implement them, because each would have required a significant additional effort and did not contribute to our aim to reach out to the general public in Africa.

Brochure success was based in part on efforts of the many talented people who donated a paragraph or a page of text, found good illustrations, did copy editing, all following professional procedures for each aspect of the production.

Distribution

Distribution is a major (and costly) endeavor. However, one of the outcomes of sending a bunch of copies to some far away university is that it makes contacts with academics in those places. In order to aid me, I hired part-time an undergraduate student at Sorbonne University. Starting with a list of African countries, we used a web browser to identify universities in each country and their mailing addresses. We then found the names of department heads and deans in departments, mainly those in the physical sciences and who had doctoral programs. In other words, we sought out people likely to have an interest in a light source. My assistant, who was bilingual (English and French), prepared address labels; each mailing was accompanied by an individual letter to that person.

I was quite pleased with the responses received, a sampling of which is at the end of this article. These included requests for more copies, offers to distribute booklets in their institutions or to neighboring ones. There also were some offers to become involved in the creation of a light source in Africa.

Marroua University in Cameroon (bilingual) hosted an annual open house for their community and requested enough copies (in both English and French) to give them to the open house participants.

Conclusions

There remain a small number of copies in each of the five languages, as well as copies of A&B which, as noted, is partly obsolete, but there are sections that can be used beneficially in teaching. To receive copies, send your mailing address, how many and which version you want to me (ernie.malamud@gmail.com).

Responses

The ALS brochure has received many positive comments and has led to contacts with academia in African universities. Many of these responses include offers to help distribute copies of ALS or help in other ways. Following are excerpts, edited for length because of the space limitation for this article.

There is obviously great value in setting up a Synchrotron facility in Africa as many of the people here in RSA partner either with Brazil or with other facilities around the world.

Dr. Charmaine Arderne, Senior Lecturer, Department of Chemical Sciences, University of Johannesburg, South Africa:

The idea of (having) a Light source in Africa is a noble idea which will advance, enhance and support cutting edge research in developing countries such as ours ... I am willing to assist you to distribute copies to colleagues in my universities and other universities in the country.

Dr. Cloud Nyamhere, Chairperson, Department of Applied Physics and Telecommunications, Midlands State University, Zimbabwe:

(Translation) I have already contacted my colleagues in other provinces....Thank you.

Professor Hery Tiana Rakotondramanana, Université d'Antananarivo, Madagascar.

I have received the brochure package and it is now ready for distribution to interested colleagues. I will let you know if we need more copies.

Dr. Cloud Nyamhere, Chairperson, Department of Applied Physics and Telecommunications, Midlands State University, Zimbabwe.

(Translation) I received the brochure. I am ready to help you distribute copies to colleagues ... at Senegalese and African universities.

Prof. Magatte Camara, Enseignant - Chercheur au LCPM, Directeur de la Recherche, de l'Innovation et de la Coopération, Université Assane Seck de Ziguinchor, Senegal.

Acknowledge receipt of your...brochure....I also talked to many physics and electronics students... Kindly, therefore, may you send more copies.

Professor Chomora Mikek, Dean, Faculty of Science, University of Malawi; Senior Research Associate, University of Johannesburg (Engineering Department); Visiting Professor, University of Rwanda, College of Science and Technology (ACE-IoT); Founder and Director for e-Communications Research Group, University of Malawi, Physics Department, Malawi

(Translation) I have started distributing the 25 brochures to Senegalense colleagues.

Professeur Magatte Camara, Enseignant - Chercheur au LCPM, Directeur de la Recherche, de l'Innovation et de la Coopération, Université Assane Seck de Ziguinchor, Senegal.

(Translation) I am convinced and want to help distribute to colleagues in Senegal's Universities, as well as other African universities.

Dr. Elhadji Babacar, Chef de Section Physique Appliquée, UFR des Sciences Appliquées et de Technologie , Université Gaston Berger - Saint-Louis, Senegal.

(Translation) The brochure may interest African researchers...of many fields. I am ready to help you distribute copies... to Cameroon and African universities.

Prof. Fridolin Tchangnwa Nya, Enseignant-Chercheur, Faculté des Sciences, Départment de Physique, Université de Marroua, Cameroon.

I am also grateful about the brochure...Our Faculty School of Agriculture and Natural Sciences, Great Zimbabwe University, is interested and willing to participate in the project... guide us on what we should do to participate in the project. I am also willing to distribute all informational material that you will send for that purpose.

Dr. Eriyoti Chikodza,Great Zimbabwe University, Masvingo, Zimbabwe.

I am glad to let you know that I am willing to assist with distribution of copies of the brochure.

Professor Brain Mapurisa, Great Zimbabwe University, Zimbabwe,

(Translation) I would like...100...brochures to distribute to... doctoral students of Physics, professors of Physical and Chemical Sciences.

Professor Fridolin Nya, Enseignant-Chercheur, Faculté des Sciences, Départment de Physique, Université de Maroua, Cameroon.

(Translation) It is an important resource to...stimulate the world wide advancement of Science, especially in the developing world. I will gladly assist in distribution and to help popularize them.

Professor Silvere Ngouela, University of Dschang, Cameroon.

(Translation) The Physics Department...will widely distribute the brochure within our University... and other African Universities (as well as) explore other collaborative paths.

Professor Pierre Talla Kisito, Chef de département de Physique, Université de Dschang, Cameroon.

(Translation) I will need more copies to distribute to students, other academics and to visitors during an Open House in October. I am a physicist specializing in material sciences

Professor Fridolin Nya, Enseignant-Chercheur, Faculté des Sciences, Départment de Physique, Université de Maroua, Cameroon.

As Vice Regent...I am available to help with distribution.

Professeur Celestin Lele, Vice Doyen chargé de la Recherche et de la coopération, Faculté des Sciences, Université de Dschang, Cameroon.

I will definitely help by distributing the materials to colleagues here at Great Zimbabwe University and also to those at sister Universities in the region…send more brochures to Mr Mapurisa. He will also assist in distributing the material.

Dr Eriyoti Chikodza, Dean, School of Agriculture and Natural Sciences, Great Zimbabwe University, Zimbabwe.

We are more than willing to participate in the distribution of the brochure.

Professor Nduduzo Phuthi, Dean of Faculty, National University of Sciences and Technology, Bulawayo, Zimbabwe.

I am willing to receive a packet of 25 more brochures which I will distribute to my colleagues.

Prof. Jean-Pierre Nguenang, Head, Department of Physics, University of Douala, Cameroon.

I am willing to distribute copies of this brochure to colleagues in the University.

Dr. W. M. Goriwondo, Office of the Dean, Faculty of Engineering, National University of Science and Technology, Biawaup, Zimbabwe.

I would be very grateful to be accorded the opportunity to work with you in distributing the brochures in Zambia and all over Africa. Please let me know when we can start.

Dr. Zulu Esau, Lecturer and Acting Head of Electrical Engineering Department, The Copperbelt University, Kitwe, Zambia.

I will be more than happy to share this information with colleagues in our university but will get back to you soon (after consultation) regarding distribution of your materials here at Mulungushi University and to other universities in Africa.

Dr. Christian Kasumo, Department of Science and Mathematics, School of Science, Engineering and Technology, Mulungushi University, Kabwe, Zambia.

(Translation) I confirm my willingness to participate in distributing copies that you send.

Dr. techn. DI Olivier Baraka Mushage, Associate Professor, Dean of Faculté des Sciences et Technologies Appliquées, Université Libre des Pays des Grands Lacs, Republique Democratique du Congo/ Goma

I am willing, in conjunction with the physics section in the Department of Science and Mathematics at Mulungushi University, to distribute your brochures and any other relevant materials on advanced light sources to other universities in Zambia and Africa. …soft copies of the brochure you can send in addition to the hard copies as it will be easier to share the brochure by email for universities that are very far from here.

Dr. Christian Kasumo, Department of Science and Mathematics, Mulungushi University, Kabwe, Zambia.

(Translation) The brochures you recently provided have been distributed to the following department and institutions: (lists over 14)

Prof. Silvere Augustin, Chef de Department de Chimie, Universite de Dschang, Cameroon.

We acknowledge receipt of the brochures. We have distributed them to our Departments namely; Chemical Engineering, Electronic Engineering, Civil and Water Engineering, Industrial and Manufacturing Engineering and Fibre & Polymer Materials Engineering. We would let you know as soon as we get feedback from the Departments. Kind regards.

On behalf of the Dean of Engineering, Université du Burundi, Dr W M Goriwondo, Burundi

(Translation) I have distributed many copies to inform my research colleagues and will continue to do so.

Dr. Aloys Katihabwa, Chef du département, Departement De Chimie, Université du Burundi, Bujumbura, Burundi.

(Translation) I am ready to distribute the copies you sent to my university colleagues.

Professor Makinta Boukar, Department of Physics, l'université, Abdou Moumouni, Niamey, Niger.

We are now planning to start a scientific activity with undergraduate students from our university and would like to share the brochure with them.

Drs. Marielle Agbahoungbata and Thierry d'Almeida, Coordinators, X-TechLab, Cotonou, Republic of Benin.

I just received the brochures you sent me by DHL and already started distributing them to my colleague and graduate students.

Professor I. Hima, Halidou, Department of Chemistry, l'université Abdou Moumouni, Niamey, Niger.

Professor Makinta Boukar, Department of Physics, l'université Abdou Moumouni, Niamey, Niger.

MSU Accelerator Science and Engineering Traineeship Program

P.N. Ostroumov, *Michigan State University*

The Michigan State University (MSU) Accelerator Science and Engineering Traineeship (ASET) Program, initiated in 2017 thanks to the U.S. Department of Energy (DOE) High Energy Physics Grant, has been very successful. ASET leverages unique campus-based capabilities at the Facility for Rare Isotope Beams (FRIB), the extensive Accelerator Science and Engineering (AS&E) faculty, the scientists at MSU and FRIB, along with resources at our partnering DOE national laboratories to create a new and unique program to produce students with competence in AS&E.

Faculty members implement the graduate student curriculum within MSU's College of Natural Science Department of Physics and Astronomy; College of Engineering departments of Electrical and Computer Engineering, Mechanical Engineering, and Computational Mathematics, Science and Engineering; and FRIB. The ASET program is part of MSU's top-ranked nuclear physics graduate program. After five years of successful enactment, the ASET program produces 5-6 graduates every year in all four areas of the critical needs of the workforce shortage: (1) physics and engineering of large accelerators; (2) superconducting radio-frequency (SRF) accelerator physics and engineering; (3) RF power engineering; and (4) large-scale cryogenic systems.

Before ASET, there were only 5-7 graduate students in AS&E at MSU. Now there are 25 (mostly Ph.D.) AS&E students in ASET. It has also developed important pipelines to recruiting student talent and placing students in DOE-lab traineeships. If funding continuity is maintained, we expect that ASET will preserve a range of 25-27 AS&E students at the Ph.D. and M.S. levels. Since the inception of the ASET Program, six students have graduated with the Ph.D., and one student has graduated with an M.S. degree. Three graduates work now in national laboratories (FNAL, LANL and SLAC), two in industry, and one in a European postdoc (with an expected return to the USA after their postdoc). All graduates work in AS&E-relevant topics. The student receiving an M.S degree has decided to continue in ASET as a Ph.D. candidate in cryogenic engineering.

In the third year of the ASET program (2019), MSU created a graduate certificate in AS&E through the efforts of the inter-department ASET leadership. This is a significant achievement and indicates MSU's broad, long-term support for the ASET program. The AS&E certificate represents an academic program certified by the university on equal standing with other MSU-certified programs. It is remarkable that the AS&E certificate was the first graduate certificate in the Physics and Astronomy Department. To date, 13 graduate students have fulfilled the requirements of the AS&E Certificate and received it. This academic year, we admitted seven new graduate students into the ASET program: five students in the Physics and Astronomy Department and two students in the Electrical and Computer Engineering Department. For their thesis research, nine students out of the 25 are now carrying out thesis research at DOE national laboratories (BNL, FNAL, LANL, LBNL and SLAC).

This year, we established the M.S. in Accelerator Science and Engineering program in the Physics and Astronomy Department and admitted the first M.S. student. The essential requirement is the same as the regular M.S. in physics, but with specific AS&E course requirements and an M.S. thesis. The AS&E curriculum linked to the M.S. program is the same as for the AS&E Certificate. This new master's program in AS&E expands the range of training opportunities under ASET and answers the request by DOE for AS&E students trained at the master's level.

ASET students are highly competitive at the national and international levels. Two ASET students, Dr. Crispin Contreras and Kellen McGee have received an SCGSR grant and conducted thesis research at FNAL. This year, Cristhian Gonzalez-Ortiz received the best poster award at IPAC'22, and Madison Howard received third prize for her poster at NA-PAC'22.

Virginia Innovative Traineeships in Accelerators (VITA) Program

G. A. Krafft, *Jefferson Lab and Old Dominion University*

https://www.odu.edu/graduateschool/vita

The Virginia Innovative Traineeships in Accelerators is the most recent DOE grant funding a physics and engineering graduate student training program. This program involves a collaboration between Jefferson Laboratory and three nearby universities: Old Dominion University, Norfolk State University and Hampton University. The first student trainees started in January of 2022 with current funding allowing for 22 two-year student graduate fellowships to be completed by the end of 2026. One important aspect of VITA is its focus on attracting and funding work of graduate engineering students.

The accelerator division at Jefferson Lab has hosted numerous graduate students in accelerator-related topics. Over the past decade and a half, graduate students have been supported at the Center for Accelerator Science (CAS) within the Department of Physics at Old Dominion University. This existing program provides a firm foundation on which to build a traineeship program.

The VITA grant allows the universities and Jefferson Lab to train students in advanced science and technology topics in broader STEM fields beyond accelerator physics with over 2/3 of the fellowships planned to be outside of accelerator physics. Existing relationships between scientists and engineers at Jefferson Lab and faculty scientists and engineers at Old Dominion University are being strengthened and broadened to include faculty and students at Norfolk State University and Hampton University as a result of VITA.

In addition to direct stipend and tuition support for students throughout their traineeships, students will have opportunities to actively engage in research and development at Jefferson Lab. They are required to take courses at the universities supporting the R&D activities they engage in and to attend available seminars and colloquia routinely presented at the universities and Jefferson Lab. They will make regular presentations on their progress.

A significant aspect of the program is the development of new training courses in accelerators. In addition to existing courses in particle accelerators, new courses are being developed on accelerator measurements, machine learning and AI in accelerators, lasers and plasma in accelerators and topics in accelerator design and engineering. Currently, the course on lasers and plasma in accelerators is being presented. Existing mechanisms allow students from any of our universities to attend and receive credit for courses presented elsewhere. Funding to allow all students to attend relevant United States Particle Accelerator School sessions exists, and the students will receive university credit for attending them.

One unique aspect of the VITA program is that a companion grant issued to our collaborating universities has just started. This DOE grant has the goal of increasing the diversity of students graduating with training related to nuclear or high energy physics. The goal is accomplished by funding their undergraduate studies and a traineeship project in association with Jefferson Lab. Old Dominion is a minority-serving institution and Norfolk State University and Hampton University are both HBCUs. It is planned to exploit this opportunity to provide an undergraduate pipeline for minority students feeding into VITA, increasing the likelihood that the students will be retained in our fields of science and technology over the long term.

The Center for Bright Beams: A Bright Spot In Accelerator Training

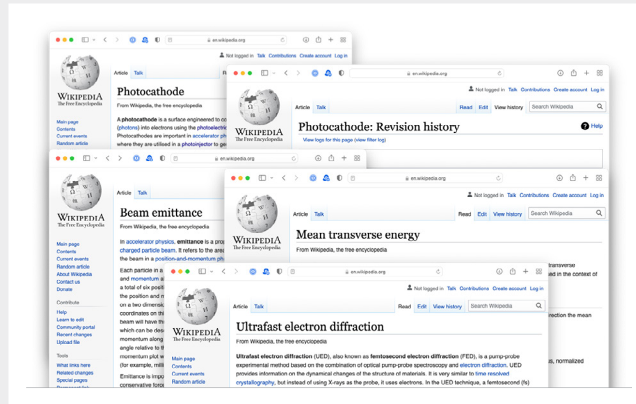
LinkedIn: https://www.linkedin.com/company/brightbeams
YouTube: https://www.youtube.com/channel/UCLLGLeOr-UUnws3RxbTK1NQ
Twitter: https://twitter.com/BrighterBeams
Facebook: https://www.facebook.com/BrighterBeams

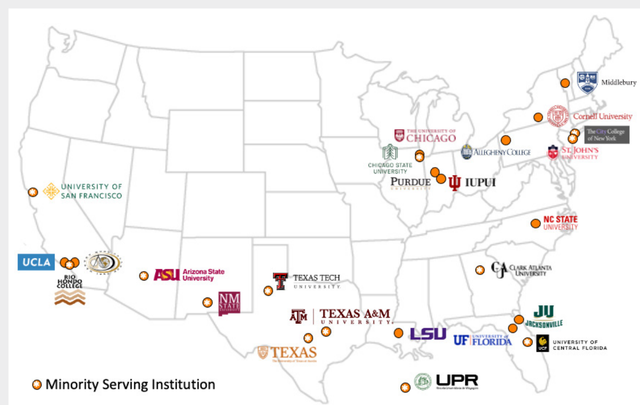
What if we could produce better beams using photocathodes designed by experts in materials science? What if superconducting RF cavities could operate at higher temperatures by engaging surface chemists and condensed matter physicists in their design? What if electron microscopes could benefit from accelerator expertise, or if beams could be manipulated at the micro level by applying artificial intelligence? What if all this work were done by students and postdocs?

These questions inspired the formation of the Center for Bright Beams (CBB http://cbb.cornell.edu), a Science and Technology Center supported by the National Science Foundation. Now in its sixth year, CBB is a collaboration of scientists from Arizona State University, Brigham Young University, University of Chicago, Cornell University (lead), UCLA, University of Florida, University of New Mexico and Northern Illinois University, as well as SLAC, Fermilab and LBL. The funding supports university-based, accelerator-driven research and — very importantly, graduate students and postdocs. To date, 45 young scientists have graduated from CBB and they have gone on to careers at national labs, academia and industry, where they are helping to meet the keen demand for scientists with accelerator expertise.

With a scientific mission to gain the fundamental understanding needed to increase electron beam brightness and reduce the cost and space requirements of accelerator technologies, CBB research spans a variety of accelerator applications. Accelerator facilities equipped with brighter, more intense beams will improve our understanding of biological molecules, facilitating powerful biopharmaceutical treatments. Compact, university-scale, x-ray free electron lasers (XFELs) and electron diffraction beamlines will increase access to x-ray crystallography of protein structures with femtosecond pulses and nanometer spatial resolution. Developing new beam control strategies for electron microscopes, which are mini-accelerators, will enable higher-resolution imaging by biologists and materials scientists.

Students are at the heart of this research. At any time, CBB supports about 30 graduate students in their thesis research, and roughly eight post-docs. About half of these work with faculty in accelerator science with the remainder in disciplines such as chemistry, surface science, microscopy and condensed matter physics. All become knowledgeable about accelerator science, and all become experts in working in a diverse team environment.

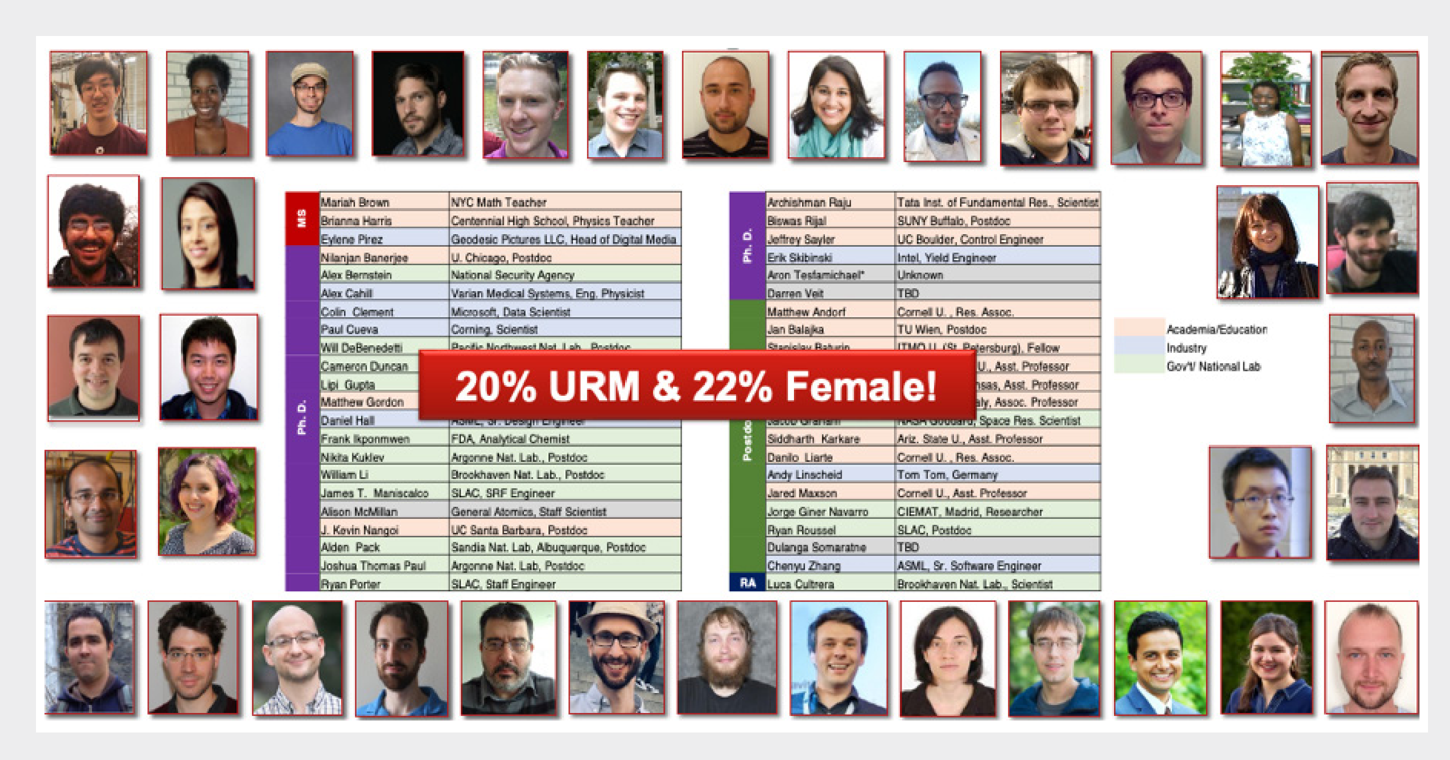




Caption: Undergraduates participate in CBB research from across the U.S.

Students get rich exposure to accelerator science. Many take courses at the U.S. Particle Accelerator School or courses at their home institution. In addition, CBB also offers mini-lectures on topics such as Introduction to RF Superconductivity, Introduction to Machine learning and AI for Accelerators and Introduction to Photoemission. To make these accessible to everyone, the lectures are also posted on the CBB YouTube channel, where the number of views now exceeds 12,000. (YouTube link: https://www.youtube.com/channel/UCLLGLeOr-UUnws3RxbTK1NQ)

Hands-on accelerator training is essential, and CBB's accelerator students and postdocs take advantage of both campus beamlines and facilities at National Labs. For example, Eric Cropp (UCLA) and Gerard Lawler (UCLA) have tuned flat beams and produced



Caption: CBB Graduate Student and Postdoc Alumni.

THz radiation at UCLA's PEGASUS. William Li (Cornell) and Matthew Gordon (U Chicago) have optimized sub-nanometer emittance beam at Cornell's MEDUSA for keV ultrafast electron diffraction. Nikita Kuklev (U Chicago) beam-tested an octupole insertion at Fermilab's IOTA and A.J. Dick (NIU) contributed to IOTA's recent demonstration of optical stochastic cooling. Lucy Lin (Cornell) worked with scientists at BNL to apply artificial intelligence (AI) techniques to tune the beam for the low energy RHIC electron cooling (LEReC), while Aasma Aslam (U New Mexico) is using artificial intelligence to tune the laser for the photoinjector at BNL's Accelerator Test Facility, and Chenyu Zhang (Cornell) tuned the optics in an electron microscope. Some of these activities, and others, are illustrated in the insets.

Recently, three students received Science Graduate Student Research Program (SCGSR) awards where they did part of their graduate research in DOE labs. Chris Pierce (Cornell) and Eric Cropp (UCLA) worked at LBL under the guidance of Daniele Filippetto on forming nanoscale patterns on the surfaces of metal photocathodes to improve the brightness of electron sources and automated beam tuning, while A.J. Dick (NIU) contributed to the demonstration of an optical stochastic cooling demonstration at Fermilab's IOTA.

Undergraduates contribute to CBB research too. Each year, about 20 undergraduates knock on CBB faculty doors and join the team; others get involved through NSF-funded Research Experience for Undergraduates (REU) programs at Cornell, the University of Chicago, Brigham Young or Northern Illinois University. All dive into research, learn about the field of accelerator physics, and are encouraged to consider a graduate degree in an accelerator-related field. Twenty past CBB undergraduates are now in graduate school!

To increase the visibility of accelerator science in the broader scientific community, CBB brings its research to conferences in materials science and condensed matter physics, in addition to conferences dedicated to accelerator physics. This year, CBB students and postdocs presented their work at the APS March meeting, the meeting of the Materials Research Society and the American Vacuum Society, in addition to the more common IPAC, NAPAC, LINAC, SRF etc. By building awareness of the interesting challenges in beam physics, CBB hopes that more students will consider accelerator science for their careers.

CBB's students and postdocs have an impact long after their time at CBB is done, through their careers in accelerator science and related fields. CBB is enormously proud of that legacy.

Development of high-performance photocathodes

Christopher Parzyck, Cornell
Alice Galdi, University of Salerno (Affiliate)
Kevin Nangoi, Cornell
Will DeBenedetti, Cornell
Kevin Nangoi, Cornell

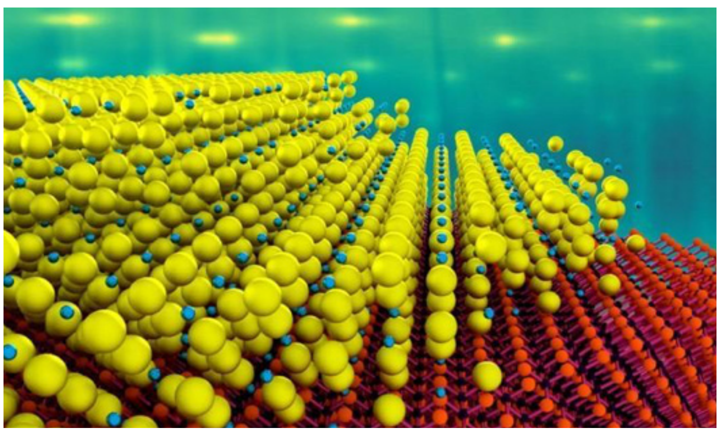
High-quality beams are often produced using photoemission. While copper photocathodes can produce superb, albeit low-current, beams, higher currents call for semiconductor photocathodes. Until recently, however, the rough surface of semiconductor materials can reduce the beam's quality by giving it unwanted transverse energy spread.

Using CBB's interdisciplinary approach, grad student Pallavi Saha (Arizona State U.), then-postdoc Oksana Chubenko (Arizona State U.), and others grew ultra-smooth semiconductor photocathodes, expected to produce beams with very low transverse energy. In a parallel effort, Cornell grad students Chris Parzyck, Kevin Nangoi and Will DeBenedetti with then-postdoc Alice Galdi combined their expertise in epitaxy, *ab initio* calculations and surface chemistry to grow the first single-crystal semiconductor photocathode, which opens a path to even lower transverse energy by capitalizing on the cathode's band structure.

With careful optimization of the beamline, the benefits of a good photocathode can be felt at the target. With that in mind, SLAC and CBB are collaborating on the photocathode and injector for the planned upgrade of the SLAC Xray FEL, LCLS-II-High Energy. Besides XFELs, applications of CBB photocathodes include colliders, ultrafast electron diffraction, and even electron microscopes.

References:

Karkare et al Phys. Rev. Lett. 125, 054801(2020) – Editor's suggestion; Bae et al. J. Appl. Phys., 124, 244903, (2018)), P. Saha et al, Appl. Phys. Lett. 120,



Artist's rendition of the Cs_3Sb photocathode atop its atomically-matched substrate. In epitaxy, the positions of the substrate atoms help to lock in the position of the atoms in the material being grown. The background shows electron diffraction data used by the group to demonstrate the atomic ordering of the photocathode surface.

194102 (2022); Parzyck et al, Phys. Rev. Lett. 128, 114801 (2022) – Editor's suggestion; C. M. Pierce, et al. Phys. Rev. Accel. Beams 23, 070101 (2020)

Ultrafast electron diffraction in a keV beamline

Matthew Gordon, U of Chicago
William Li, Cornell
Cameron Duncan, Cornell

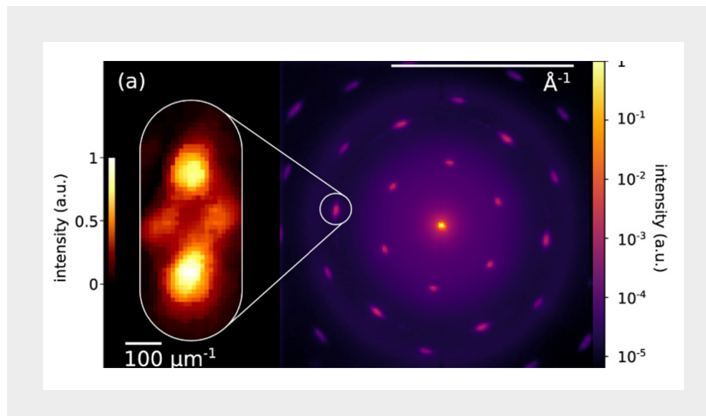
Like X-rays, a coherent electron beam scattered from a crystalline material forms a diffraction pattern. Such beams can have fs bunch lengths allowing them to probe fast dynamics, and in principle, they can have high transverse coherence, enabling diffraction from crystals with large unit cells. Much previous work in UED has rightly focused on generating short bunch lengths for extreme time resolution.

Recently, grad students Cameron Duncan (Cornell), William Li (Cornell) and Matthew Gordon (U Chicago) used a high-performance semiconductor cathode to produce an electron beam for keV ultrafast diffraction. The emphasis here was to reduce the transverse beam size dramatically, to allow the study of small samples that are hard to fabricate as large crystals. After tuning to avoid expansion of the beam from space charge [ref], using optics that correct aberrations up to sextupole order [ref], and passing the beam through a pinhole, the normalized emittance is under a nanometer-rad and has a temporal resolution about 200 femtoseconds.

So far, this beam has produced a diffraction pattern from a twisted bi-layer whose large structure measures 10 nm. Future work will include the study of thin film heterostructures, and to perform ultrafast electron spectroscopy with high energy resolution.

References:

M. Gordon et al. Phys Rev Accel. Beams, Phys. Rev. Accel. Beams 25, 084001 (2022)); W. H. Li, C.J.R. Duncan, et al., Structural Dynamics 9, 024302 (2022)



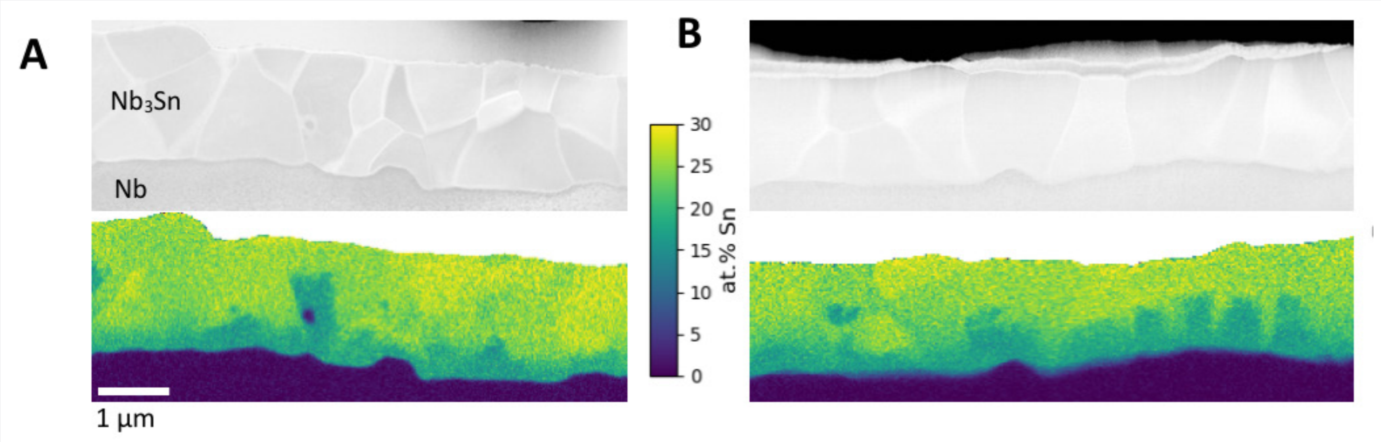
Diffraction pattern produced by a keV electron beam incident on a pair Single hexagonal atomic layers of $MoSe_2$ and WSe_2 with a relative rotation of XX degrees. The brightest diffraction spots arise from the individual layers, while the small satellites arise from the Moire superstructure. The beam emittance was 0.7 nm-rad.

Accelerators for cleaner wastewater

Nathan Sitaraman, Cornell
Zhaslan Barraisov, Cornell
Ryan Porter, Cornell

Nb_3Sn is a next generation material for superconducting accelerating cavities. Unlike traditional niobium cavities, Nb_3Sn cavities can operate at higher temperatures, eliminating the need for expensive and complex cryogenic refrigeration systems. As a result, Nb_3Sn opens the door to far wider application of high-power beams.

In prior efforts to coat superconducting accelerating cavities with Nb_3Sn, the Nb_3Sn layer exhibited two structures with different critical temperatures. One of these had a high critical temperature (Tc), consistent with expectations for ideal Nb_3Sn, while the other had a lower Tc with degraded performance. Working together,



Caption: A (top) Dark field scanning TEM image of a Nb_3Sn layer grown on Nb using standard vapor diffusion. This growth method results in a rough Nb_3Sn surface atomic Sn concentration map (bottom) determined using Energy Dispersive X-ray Spectrometry (EDX) and showing Sn deficient grains and Nb inclusions. B (top) Nb_3Sn layer grown on Nb using the new electrodeposition method. This growth method results in smooth Nb_3Sn surface (bottom) and uniformly rich Sn deposition on the surface. While the Sn composition decreases near the Nb3Sn/Nb interface, there are no Nb inclusions or voids.

CBB grad students Nathan Sitaraman, Zhaslan Barraisov and Ryan Porter combined their ab initio calculations, microscopic sample characterization, and growth expertise to diagnose the problem and modify the Nb_3Sn growth procedures, resulting in better uniformity and a 50% reduction in intrinsic energy losses.

CBB is sharing its procedures with scientists at JLAB and Fermilab, who are now assembling the first full-scale Nb_3Sn accelerating cavities. Future Nb_3Sn cavities could increase the performance of high energy accelerators and enable new environmental applications such as the purification of city wastewater in order to eliminate parasites, pharmaceuticals and other persistent contaminants.

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Machine Learning-based tuning of Electron Microscopes

Chenyu Zhang, Cornell

Today's electron microscopes are complicated devices with aberration correction involving hundreds of optical elements like those found in accelerators and synchrotrons. The beam alignment can only be effectively monitored at the end of the column, usually using an interferogram called a Ronchigram (see figure) that maps the phase variation of the beam versus scattering angle. One challenge to tuning is that the aberrations are poorly behaved, with cusp-like minima that are very unstable — as a result, full tuning is tedious and requires hours of effort even for an expert.

To address the problem, CBB postdoc Chenyu Zhang showed that emittance (the volume of phase space occupied by the beam) is an alternate metric of beam quality and is better behaved than the aberration function. Next, he applied Bayesian optimization techniques to automatically tune the 81 correcting lenses related to the octupole aberration in a NION UltraSTEM microscope. Tuning was rapid, taking less than two minutes, gaving results as good as the current hand-tuning — and required no operator experience.

CBB is now applying these techniques to other aberrations and microscopes. Once this is done, the goal is to transfer these methods to microscope companies, so that future microscopes can be automatically tuned, and users can avoid expensive and time-consuming visits by company experts.

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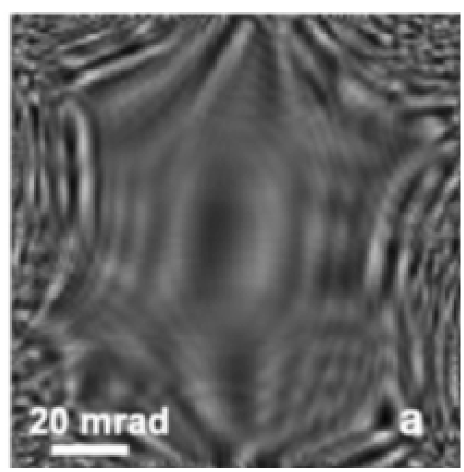

Ronchigrams like this one map the phase variation of the electron beam with scattering angle in an electron microscope and should be smooth when the microscope is properly tuned. CBB has shown that minimizing a microscope's emittance yields a Ronchigram with the desired features.

Machine learning-based live optimization of accelerators

Lucy Lin, Cornell

The complexity of tuning particle accelerators, with their diverse components and sometimes complicated beam dynamics, makes tuning an obvious, but challenging target for machine learning techniques.

Recently, CBB student Lucy Lin applied machine learning techniques to cooling at RHIC at BNL (LEReC). A specialized Bayesian optimization algorithm maximizes the cooling rate using a high-dimensional surrogate model trained on LEReC system simulator data. In tests, this system, which was developed in a collaboration between CBB and BNL, has automatically tuned beams to the orbit that maximizes cooling. This success makes full integration with the RHIC control system very promising.

This is just one of several CBB efforts to apply machine learning to accelerator tuning. Other target accelerators include HiReS at LBL, the Cornell Electron Storage Ring, Argonne's AWA and UCLA's PEGASUS. As illustrated in the figure, the accelerators under study span a wide range of parameters and goals, affording an opportunity to probe the bounds of applicability of artificial intelligence techniques to the manipulation of beams.

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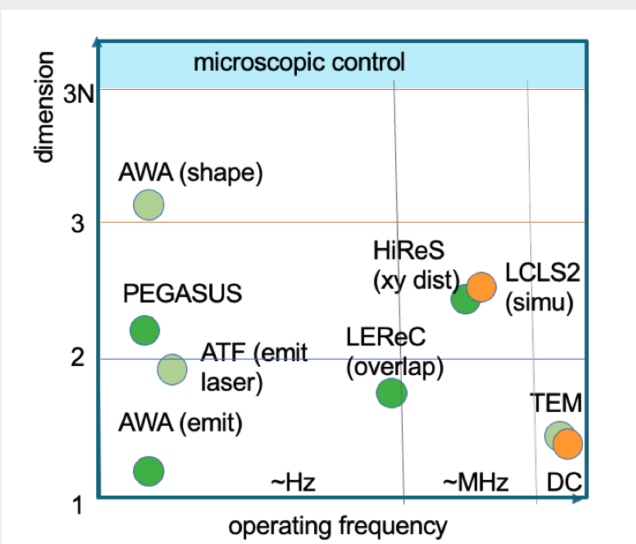

The accelerators under study span a wide range of parameters and goals, affording an opportunity to probe the bounds of applicability of artificial intelligence techniques to the manipulation of beams.

A new frontier in beam cooling

AJ Dick, NIU
Sam Levenson, Cornell

The scientific reach of a stored beam – for example, the luminosity in a collider — is limited by deleterious effects that increase the beam's disorder. These effects can be mitigated by "cooling" the beam, but conventional cooling is ineffective for beams with very high brightness. One approach to cooling very bright beams is "optical stochastic cooling," in which radiation from the beam is emitted and feedback onto itself in such a way that it reduces the beam's disorder.

Recently, optical stochastic cooling was demonstrated for the first time at Fermilab's IOTA ring. CBB grad student AJ Dick of NIU contributed to the system used to synchronize the emitted radiation with the beam to sub-optical wavelength precision. He also implemented a model of OSC in the widely used particle tracking code, elegant, and simulated IOTA's cooling in detail using this model (see figure).

The next step is to amplify the emitted light before it rejoins the beam, and CBB's Matt Andorf, together with colleagues at Fermilab and Argonne National Lab, have developed an initial design. In the longer term, CBB aims to demonstrate cooling on a larger scale at CESR. A design for the beamline has been completed in BMAD. Modeling is complete, and a system for stabilizing the beam developed by CBB grad student Sam Levenson is promising.

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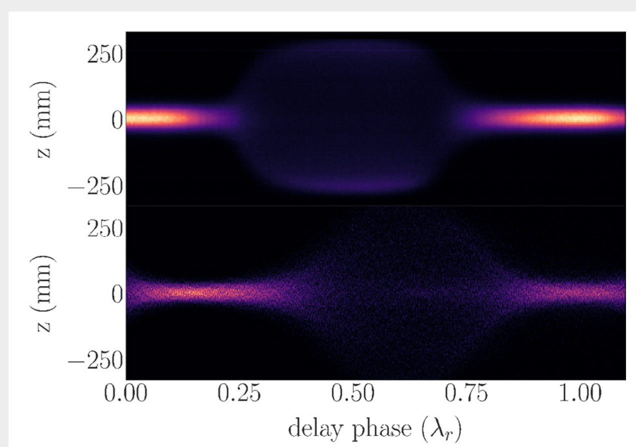
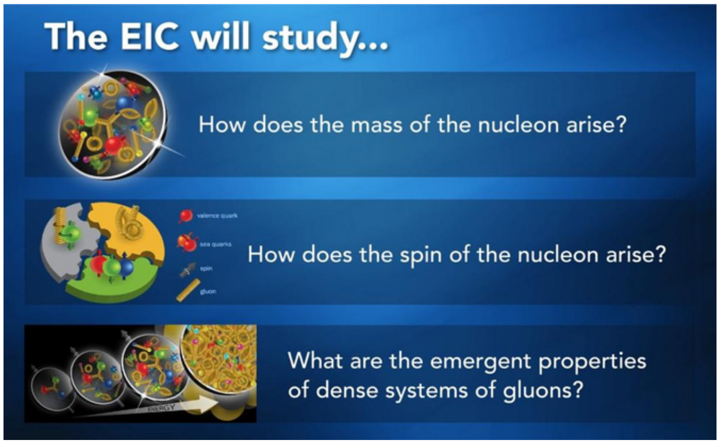


The accelerators under study span a wide range of parameters and goals, affording an opportunity to probe the bounds of applicability of artificial intelligence techniques to the manipulation of beams.

The Electron-Ion Collider

Christoph Montag, *Brookhaven National Laboratory,* **and Todd Satogata,** *Thomas Jefferson National Accelerator Facility, for the EIC Design Team*



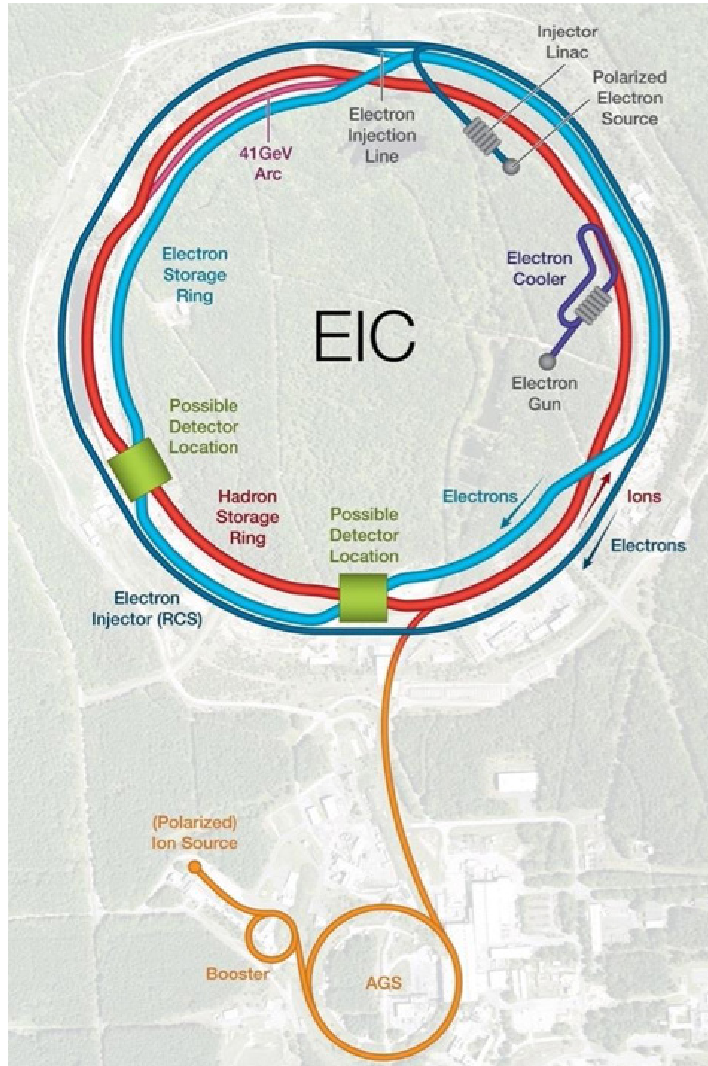


Figure 1. Schematic diagram of the EIC layout.

Current Design Features of the Electron-Ion Collider

The Electron-Ion Collider (EIC) will enable study of how partons (quarks and gluons) form nuclear matter and will uniquely address profound questions of nuclear physics involving details of nuclear structure at the quark-gluon scale (see info graphic [1]). To address these questions, the EIC will provide polarized electron-proton and electron-ion collisions over a center-of-mass (CM) energy range of ~30 to 140 GeV, with luminosities up to 10^{34} cm^{-2} s^{-1}.

The U.S. Department of Energy (DOE) approval of mission need (CD-0) was granted for the EIC in December 2019 [2], and CD-1 followed in June 2021. The EIC is being constructed at Brookhaven National Laboratory (BNL) as a unique DOE project partnership between BNL and Thomas Jefferson National Accelerator Facility (TJNAF). This partnership has matured and deepened since CD-1.

EIC Overview

A schematic diagram of the EIC layout is shown in Figure 1. The EIC will take advantage of the entire Relativistic Heavy Ion Collider (RHIC) facility at BNL, including RHIC magnets, injectors and tunnel enclosure. The two existing large experimental halls and interaction regions (IRs) are at IR6 (STAR) and IR8 (sPHENIX). The Hadron Storage Ring (HSR), constructed from RHIC modifications, the new Electron Storage Ring (ESR) and the Rapid Cycling Synchrotron (RCS) electron injector will all be co-located in the existing RHIC tunnel. The polarized electron injector gun and linac will be located at IR12, and an energy-recovery linac (ERL) for hadron beam cooling will be constructed at IR2. Hadrons will circulate counter-clockwise in the HSR, while electrons will circulate clockwise in the ESR and RCS. A new high-luminosity IR for the new EIC detector will be constructed at IR6.

Table 1 lists the EIC parameters at the maximum luminosity CM energy E_{cm}=105 GeV, achieved by colliding 275 GeV polarized protons and 10 GeV polarized electrons. The overall facility design strategy and main parameters have remained stable since CD-1 [3]; they satisfy the design requirements without exceeding fundamental beam dynamics limits. In particular, the design parameters remain within the limits for maximum beam-beam tune-shift parameters (hadrons: $\xi_p \leq 0.015$; electrons: $\xi_e \leq 0.1$) and space charge parameter (≤0.06), as well as beam intensity limitations and IR chromaticity contributions.

EIC Luminosity and Detector

Figure 2 illustrates the EIC luminosity versus CM energy over the required range of 30-140 GeV. Proton beam energies are shown in blue, and electron beam energies are shown in red, with the maximum luminosity achieved with beam energies and parameters shown in Table 1. The facility luminosity is limited by different effects at different collision energies. At the lowest center of mass energy, maximum acceptable hadron space charge tune shift limits the permissible hadron beam current. As this constraint is loosened with higher hadron beam energies, the design enters a region where the luminosity is limited by acceptable beam-beam tune shifts in both beams.

At 10 GeV and higher, the electron beam current is limited by the installed RF power that replaces the synchrotron radiation power emitted by the electron beam. The installed RF power of 10 MW is not an intrinsic technical limit but is rather a design choice to balance facility performance with construction and operations costs. The electron beam's current and achievable luminosity become limited by the available RF power and synchrotron radiation losses for electron beam energies beyond 10 GeV, corresponding to CM energies beyond 100 GeV.

A single high-luminosity IR and detector will be installed in IR6 as part of the project. The EIC Detector Proposal Advisory Panel reviewed detector collaboration proposals and, in March 2022, unanimously identified the ECCE design proposal for construction as the first EIC detector [3]. The new collaboration is named ePIC, and rapid progress is being made on detector design to satisfy project CD-2 requirements.

The luminosities in Figure 2 are shown for a single collision per turn, or with a single operational detector. The overall design accommodates a second interaction region and detector to be constructed later at IR8. To avoid unacceptably large beam-beam effects from multiple crossings per turn, these two detectors would share luminosity in an operational mode where the total luminosity at the two collision points equals the luminosity for operations with a single interaction point.

Parameter	Protons	Electrons
Center-of-Mass Energy [GeV]	105	
Energy [GeV]	275	10
Number of bunches	1160	
Particles per bunch [10^{10}]	6.9	17.2
Average beam current [A]	1.0	2.5
RMS emittance [nm]	11.3 / 1.0	20.0 / 1.3
β* [cm]	80 / 7.2	45 / 5.6
Beam divergence at IP [mrad]	0.119 / 0.119	0.211 / 0.152
Beam-beam parameter $\xi_{x,y}$	0.012 / 0.012	0.072 / 0.100
IBS growth time (long/horz) [h]	2.9 / 2.0	--
Synchrotron radiation power [MW]	--	9.0

Table 1. EIC Parameters at Maximum Luminosity.

EIC Accelerators [5]

The EIC pre-injector will provide 2×7 nC bunches within 2.5 μs. The 2.856 GHz linac will operate at 100 Hz to provide four pairs of bunches, with 10 ms spacing between pairs. A total of 8 bunches (4 pairs) will be provided at a repetition rate of 1 Hz to the RCS. The polarized electron beam will be generated from a high-voltage (HV) DC gun with a strained superlattice photocathode. The EIC HVDC polarized gun prototype has achieved a polarized electron beam with 7.5 nC bunch charge and 37.5 μA average current without QE decay [6].

The RCS will merge the two batches of 4 polarized electron bunches from the linac into two 28 nC bunches and then accelerate them in 1 Hz cycles to the ESR collision energy of 5 to 18 GeV. This scheme continuously replaces stored bunches in the ESR to facilitate arbitrary spin patterns and ensure high average polarization in both spin states. A dedicated design with high periodicity ensures that no depolarizing resonances are encountered during the entire energy ramp. This concept has been validated in extensive spin tracking studies that realistic machine imperfections such as misalignments.

The ESR has many similarities to high-intensity electron storage rings, such as the B-factories of KEK and SLAC, and will benefit from the technologies established by those facilities. It will consist of normal-conducting magnets arranged in a FODO cell structure. To achieve the horizontal design emittance of 24 nm over the entire energy range from 5 to 18 GeV, the betatron phase advance per FODO cell is set to 90 degrees at 18 GeV and 60 degrees for 5 and 10 GeV. Super-bends with adjustable reverse bends in the arcs are employed at 5 GeV, both to achieve design emittance and to provide additional radiation damping to allow for a beam-beam parameter as high as ξ_y = 0.1. A superconducting 591 MHz RF system replenishes the radiation losses and provides the necessary longitudinal focusing. The ESR plane is tilted with respect to the

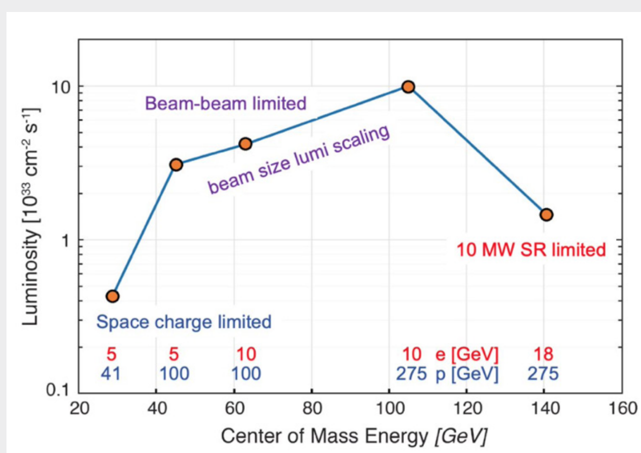


Figure 2. EIC luminosity as a function of center-of-mass energy.

HSR by 200 μrad around the axis through IP6 and IP8 to facilitate the necessary crossing of the two rings in IRs 4 and 12 without vertical orbit excursions in either ring.

The HSR comprises arcs from both the "Blue" and the "Yellow" RHIC rings. The straight sections connecting these arcs will be rebuilt to suit their purpose. The existing RHIC injector complex will continue to be used for HSR injection; the transfer line will be extended to the IR4 straight section, where the fast injection kickers can be accommodated. A strong hadron cooling system to counteract intra-beam scattering will be installed in IR2, which requires extensive modifications to the straight section lattice there.

To accommodate the large hadron energy range from 41 to 275 GeV (for protons), while keeping hadron and electron beams synchronized, the circumference of the HSR must be adjusted accordingly. Between 100 and 275 GeV, this is accomplished by a radial shift. At 41 GeV, an "inner" arc between IRs 10 and 12 is used instead of the outer arc (Figure 1), reducing the HSR circumference by approximately 90 cm.

The HSR superconducting magnets will be retrofitted with copper-clad stainless-steel screens to reduce resistive wall heating due to the short bunches and high beam current. In addition, these screens will be coated with amorphous carbon to reduce the secondary electron yield, thus suppressing electron cloud build-up.

Intrabeam scattering (IBS) and beam-beam effects will degrade the beam emittance in the HSR over the length of each store, limiting integrated machine luminosity. It is necessary to cool the hadron beam to counteract these effects and maintain high luminosity during long collision runs. The EIC high luminosity parameters were optimized to have an IBS growth time of about two hours. A proposed cooling method called Coherent electron Cooling (CeC) was selected as the baseline for EIC due to its high cooling rate. The current design, simulated using a 1D cooling code, promises sufficient cooling rates to counteract IBS at 275 GeV and 100 GeV, with 3D cooling studies underway. Hadron beams will also be pre-cooled at 24 GeV by the ERL.

Electron and hadron beams collide under a total crossing angle of 25 mrad, requiring beam crabbing in both the HSR and ESR. Focusing is provided by superconducting low-β quadrupoles, some of which share a common yoke. To compensate for betatron coupling induced by the detector solenoid, some of these superconducting magnets will be equipped with an additional skew-quadrupole coil. This scheme will also compensate for the effects of the tilted ESR plane.

Beam Dynamics

The challenging beam parameters in the EIC collider rings require careful study of a large variety of related beam dynamics effects, such as dynamic aperture, collective effects, beam-beam effects and polarization.

Dynamic aperture (DA) studies have been performed for both collider rings. A significant reduction in DA is observed in the HSR from crab crossing, compared to that with head-on collisions without crabbing. The IR magnet field errors must therefore be controlled to within one unit to ensure sufficient HSR DA. ESR DA studies have focused on the most challenging scenario: the 18 GeV, 90-degree lattice with two interaction regions. The minimum goal of 10σ in all three planes has been successfully demonstrated based on a novel chromatic compensation approach.

With beam currents as high as shown in Table 1, collective effects are a serious concern in both rings, and vacuum system components must be designed and optimized to a high degree. The ESR single-bunch instability threshold is above requirements for stable operation; the large beam-beam tune spread of up to $\xi = 0.1$ provides sufficient Landau damping to counteract transverse coupled-bunch instabilities. An ESR longitudinal damper is planned to limit coherent longitudinal oscillations that are detrimental to the hadron beam emittance via crab cavity arrival time and beam-beam interactions.

Collision parameters have been optimized to minimize hadron beam emittance growth rates while simultaneously retaining high luminosity. The unique beam-beam dynamics with crabbing is being studied to ensure the attainability of the large beam-beam parameters. Weak-strong simulations indicate that stable operations can indeed be achieved, given a careful selection of machine parameters, such as working points. Strong-strong simulations suffer from numerical effects due to the limited number of macroparticles. Studies are underway to understand these models and develop a scaling law that allows extrapolation of the obtained strong-strong growth rates to the actual number of beam particles. Strong-strong coherent beam-beam effects have been studied, with threshold onset at twice design intensities.

Multipole components of the crab cavity fields are a potential concern due to the time-dependent nature of these fields and their modulation with the synchrotron frequency. Simulation studies are being performed to establish the required field quality tolerances. The effect of crab cavity RF noise on hadron beam emittances has been investigated.

Extensive spin matching for the ESR has resulted in an equilibrium polarization of 30 percent at 18 GeV in presence of misalignments, which is the most challenging operating scenario. With continuous bunch replacement, this ensures an average polarization during operations of 70 percent, even at 18 GeV.

Conclusion

In conclusion, the EIC partnership project between BNL and TJNAF capitalizes on each lab's strengths with well-defined scope ownership and a commitment to seamless inter-lab collaboration. The EIC project is moving forward with a mature design to deliver a world-class, unique complex that will enable unprecedented exploration of fundamental nuclear physics questions.

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Accessible Exascale Simulation Tools for Particle Accelerators and Beams

Axel Huebl and Jean-Luc Vay, *Lawrence Berkeley National Laboratory*

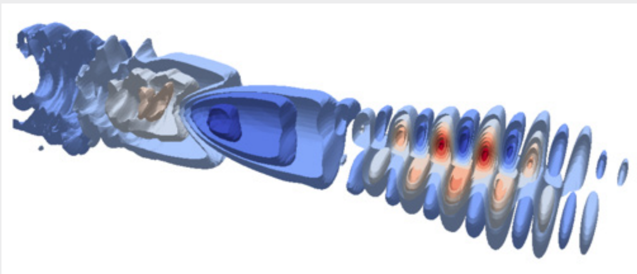

Figure 1. Snapshot of a 3D WarpX simulation showing the longitudinal electric field of a laser-wakefield accelerator. The laser pulse (right) and the plasma wakefield (left) can be modeled using a Lorentz-boosted reference frame, reducing computational time. All computations in the figure - including the live visualization rendered in this figure - are further sped up by running on the latest graphical processing units (GPUs).

Particle accelerators for high-energy physics experiments are some of the most complex and challenging devices built in human history. From design to construction, operation and analysis, these modern "cathedrals"[1] are multi-generational and cross-expertise projects. This requires extraordinary levels of explicit cooperation and coordination of large teams over decades. In such generational time frames, it is essential that science results, data, software tools and ongoing developments are readily accessible for new members that want to join the community.

Beam & Accelerator Modeling: Status & Vision

In today's accelerator and beam research, computer modeling is essential. Simulations guide the exploration of novel sources, design of lattices for acceleration, transport and storage model the beam dynamics up to application and interaction. In some cases, recent data-driven models are even fast enough to run in tandem with operations.

As the level of sophistication and complexity of particle accelerators increases over time, so does the complexity of beam and accelerator simulation tools. Indeed, as noted in the Snowmass21 Computational Frontier (CompF) report: "The size and complexity of [High Energy Physics] Software & Computing are now commensurate with that of experimental instruments."[2] Just as large particle accelerators need a high level of coordination, development and maintenance, so does the simulation software that supports them.

It is especially key at a moment where the design of the next generation of colliders is heavily constrained by size, cost and energy consumption, pushing for the development of so-called "advanced concepts" that could be used in the future in place of or in addition to existing collider technologies. The development of these new technologies depends critically on computer simulations. In particular, one of the technologies that promises accelerating field gradients that are orders of magnitude higher than with RF structures, plasma-based acceleration, poses the most extreme demands on computing needs.

Closing out the Snowmass21 community planning exercise in Seattle earlier this year, the community conducted a broad review of the status and needs of accelerator and beam physics modeling and notes that "Despite accelerator physics being a field with extreme levels of coordination and long-range planning for the research, design, construction and operation of its largest accelerator complexes, e.g., at CERN or at Fermilab, the development of beam and accelerator physics codes has often been largely uncoordinated."[3]

The community paper also went on to formulate a vision, which includes developing a comprehensive portfolio of particle accelerator and beam physics modeling tools that are robust, accessible, fast and extensible to address accelerator and beam physics thrust "grand challenges" on intensity, quality, control and prediction.[4] The prediction grand challenge focuses on the development of "virtual particle accelerators."

Among other recommendations, the community advocates to "Develop efficient and scalable software frameworks and associated tools to effectively leverage next generation high-performance and high-throughput computing hardware."[3] This includes efficient use of desktops to medium-size computer clusters to the largest available supercomputers, including the 21 MW supercomputer Frontier at OLCF, see Fig. 2. Those are all needed to enable high-fidelity modeling of particle accelerators that include highly resolved modeling of dynamic beam evolution with long-term stable models, and their interactions with all components of the beamline.

Key to the success and impact of the next generation of beam and accelerator simulation software is the accessibility to the simulation tools, their models, their designs and their implementations. This drives the community to go beyond the current status of uncoordinated developments of simulation codes, toward the development of open-source ecosystems with standardized data handling and user interfaces.

Exascale Computing for Accelerators

Four years have passed since we reported in this newsletter on the start of the U.S. Department of Energy's Exascale Computing Project (ECP) and our research contribution on staging for laser-wakefield acceleration towards future lepton colliders.[5,6] ECP had selected the particle-in-cell code WarpX as one of 25 ECP application projects — the only one in accelerator physics in the entire DOE portfolio. This summer, WarpX achieved a significant highlight[7] by being the first ECP science application that ran on the full size of *Frontier* — the first ever reported supercomputer that breaks the 10^{18} calculations per second hallmark.

WarpX is, from the ground up, built for the latest supercomputer hardware, which at exascale is dominated by fully new architectures.

Figure 2. The world's first exascale supercomputer Frontier at Oak Ridge National Laboratory has been launched this year.

[8] Over the last decades, CPU-based architectures that routinely provided faster clock frequencies sped up codes without significant need for code maintenance. This trend, driven by Moore's Law, has come to an end. New architectures, spearheaded by GPUs and mobile processors, use a reduced instruction set and highly increased parallelism, at moderate, energy-conserving clock speeds. Further diversification can be expected,[9] such as a mainstream adoption of FPGAs and specialized hardware components from linear algebra to data streaming. Compared to prior decades, this is close to a "Cambrian explosion" of computing platforms.[9]

With fundamental changes in hardware, software data structures and calculation routines had to be redesigned — and robust numerics that can scale to large scales in parallelism and simulation time had to be researched. Following industry trends, formerly prevalent Fortran programs are now mostly written in modern C++. Modern C++ provides syntax for algorithms to be written in an abstract way that can, with near-zero runtime overhead, run on the above mentioned, diverse compute architectures — by delegating the complexity to compilation time and performance-portable library design.[10]

Integrated Software Ecosystem

When developing modern modeling software, rewrites become necessary periodically. In that regard, our team is in the process of modernizing the accelerator modeling codes in the Beam, Plasma & Accelerator Simulation Toolkit (BLAST),[11] spear-headed by the time-based 3D particle-in-cell (PIC) code WarpX. Further BLAST PIC codes, such as the plasma-wakefield code HiPACE++[12] (lead: DESY) and the s-based beam dynamics code ImpactX[10] are now leveraging ECP software components to also get ready for Exascale hardware by reusing common PIC components as library modules. Figure 3 shows the productive interplay of hardware vendor and computer science dependencies building the foundation; numerical and HPC libraries providing the middle-ware, with applications sitting on the top. The framework can be used as a conventional physics application — or as a modular toolset that can be tuned in fine detail for concrete science cases by writing user-friendly, platform-agnostic scripts. Such design also fosters sustainable development, reusing the expertise that galvanized into tested and tuned methods instead of "reinventing the wheel."

WarpX has now been developed as open source for a few years and is mature enough to be adopted by users. Besides its core application area in ECP, laser-wakefield acceleration, first high-impact work by users includes beam-driven wakefields, laser-ion acceleration, fusion devices, astrophysical plasmas, high-performance computing and the design of thermionic converters and microelectronics in spin-off projects. HiPACE++ recently elucidated the recovery time of a plasma-wakefield accelerator.[13] The latest BLAST code for beam dynamics, ImpactX, recently entered the testing phase.[11]

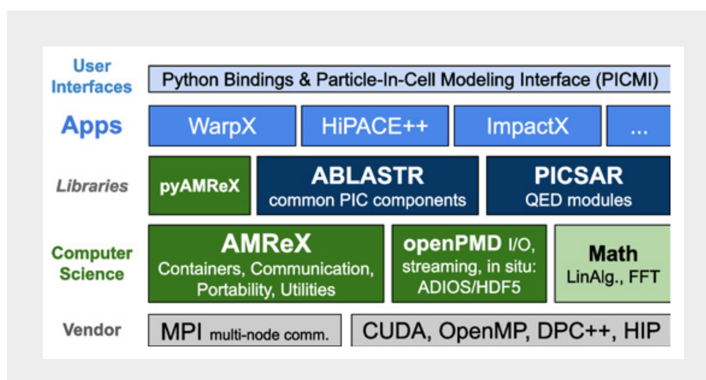

Figure 3. Design of the open source BLAST software stack. Modularization enables code sharing and tight coupling.[11] Standards for user inputs (particle-in-cell modeling interface, PICMI)[15]and data (openPMD)[16] form the basis for a compatible ecosystem of codes.

Accessibility of Simulation Tools

Startup-up burdens to simply use a modeling tool or even better, to contribute new ideas into it, need to be reduced to a minimum to ensure productive collaboration. Accessibility for new members joining the accelerator modeling field starts with finding common language and ensuring open communication of concepts, methods, implementations and their usage.[14]

As an analogy of openness to new ideas, transitioning to new fundamental code languages for accelerator modeling is not too different from the need to stay curious and in conversation about how to combine existing and advanced accelerator concepts. Simulations that can model both conventional beam dynamics and advanced concepts can play a vital role to explore and characterize various concepts. This can help define the common language which makes exciting worlds accessible to each other, e.g., plasmas & accelerators or modern programming languages in HPC & user-friendly modeling. In our opinion, this can best be achieved by following the open science approach: open source software, open access to documentation, open data, and data standards.

Inspired by the success of working openly in interdisciplinary teams to achieve Exascale, the newly started SciDAC-5 Collaboration for Advanced Modeling of Particle Accelerators (CAMPA) strives to develop *virtual test stands* for cutting-edge experiments in accelerator science. Transcending individually specialized 1
modeling expertise and accelerator modeling codes or frameworks, teams from LBNL, SLAC, Fermilab, UCLA, ANL and ORNL will build a cohesive and interoperable modeling ecosystem that speaks the same "language," e.g., in the description of parameters of beams. A shared language can keep up with the complex modeling needs of future beamlines. Multidisciplinary teamwork between accelerator physicists, computer scientists, software developers and applied mathematicians will ensure that modeling is at the forefront of computing capabilities.

At the center of this ecosystem will be common standards to control simulations and exchange information. For instance, common user control will be possible in a scripting language, i.e., the Python standard PICMI,[15] that simplifies the design and optimization of beam sources, storage and transport. Accompanying documentation and easy installation logic are essential to deliver productivity and accessibility for new community members. Continuous correctness benchmarks with tests against prior codes and analytically solvable systems will ensure code robustness — in combination with open source development and code reviews.

For data exchange, the community has developed and adopted the open metadata standard for particle and mesh data (openPMD),16 which enables chaining of simulation codes and integration of experimental diagnostics based on scalable computer science data backends, such as HDF5[17] and ADIOS.[18] Just like software, openPMD data standard updates are developed in versions and accompanied by a well-supported open source ecosystem of tools and integrations. Contributors span across multiple international labs, from Berkeley Lab to Helmholtz in Germany and CEA in France over further DOE labs and universities.

The development and adoption of such standards means that the ecosystem is extensible to any other code or framework that also supports those standards, opening the door to a community-wide ecosystem of interconnected accelerator modeling tools that will offer endless new possibilities.

Enable Tight Coupling with AI/ML

Based on such modular and compatible software interfaces and standardized data, the integration of novel data-driven approaches in machine learning opens new possibilities. For instance, the BLAST framework is currently upgraded to couple even its most central calculation routines to equally GPU-accelerated AI/ML frameworks. Such coupling will enable *in situ* ML training & inference of detailed segments of a beamline, e.g., plasma elements, with a high-fidelity code such as WarpX. These trained models could then be used as a surrogate representation in long-time particle tracking and storage models, such as ImpactX. Likewise, surrogates can be used for fast optimization and assist operation of experiments.

Exciting Times Ahead for Accelerator Modeling

Extrinsic challenges from significantly evolving computing hardware requires the community to act sustainably by openly sharing, maintaining and contributing code to keep pace. Intrinsic challenges in sustainable particle accelerator design will at the same time require complex combined modeling and orders of magnitude faster codes to combine simulations, data methods and operations. In our vision, an innovative and well-maintained open source software ecosystem will be one important component to reach that future.

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Six Dimensional Distributions at the SNS Beam Test Facility

Kiersten Ruisard, Alexander Aleksandrov, and Austin Hoover, *Oak Ridge National Laboratory*

Motivation

Real machines are always different, and frequently very different, from design. Improving and adapting simulation codes to better agree with reality is a continuous goal in accelerator physics. Good agreement enables the precision use of codes to make decisions based on realistic beam distributions. This is especially important in hadron accelerators where beam loss is a constant concern. This article describes active research at the Spallation Neutron Source (SNS) Beam Test Facility (BTF) aimed at improving simulation model accuracy, motivated by the desire to predict patterns of observed beam loss.

Beam loss occurs when a particle scrapes on the vacuum chamber boundary. The SNS linac is outfitted with over 400 beam loss monitors which localize losses along the linac. Measured loss patterns are not currently recoverable by simulation. In fact, the best "low loss" solution in practice may give a simulation result that predicts high losses.

The control of beam loss is a crucial requirement for high-power accelerators, as excessive losses lead to an unserviceable facility. Even as beam powers increase, the tolerable loss floor remains fixed. More effective strategies are needed for future state-of-the-art facilities[1]. One mechanism for loss is halo, a low-density population of particles outside the beam core. Halo, which is driven by a combination of collective and nonlinear effects[2], can be generally defined as excess density at least four orders of magnitude below the peak density. Another important mechanism for H- machines is intrabeam stripping at high charge density[3]. We discuss only the first mechanism in this article.

Lower losses could be sought through accelerator design minimizing the halo formation or through aggressive halo collimation; both require accurate predictions of the halo extent along the beamline. As this requires self-consistent modeling of forces on the beam, the best tool is the particle-in-cell (PIC) algorithm. With modern computing power, it is feasible to track many millions of particles from source to target with high precision; however, the typical model-measurement discrepancy is orders of magnitude higher than the halo and loss levels (e.g., [4,5]). This discrepancy is not expected to be caused by a failure of the codes or "missing physics." Instead, it is more widely attributed to the complexity of accelerator systems and the lack of precise knowledge of all relevant parameters including the initial particle distribution.

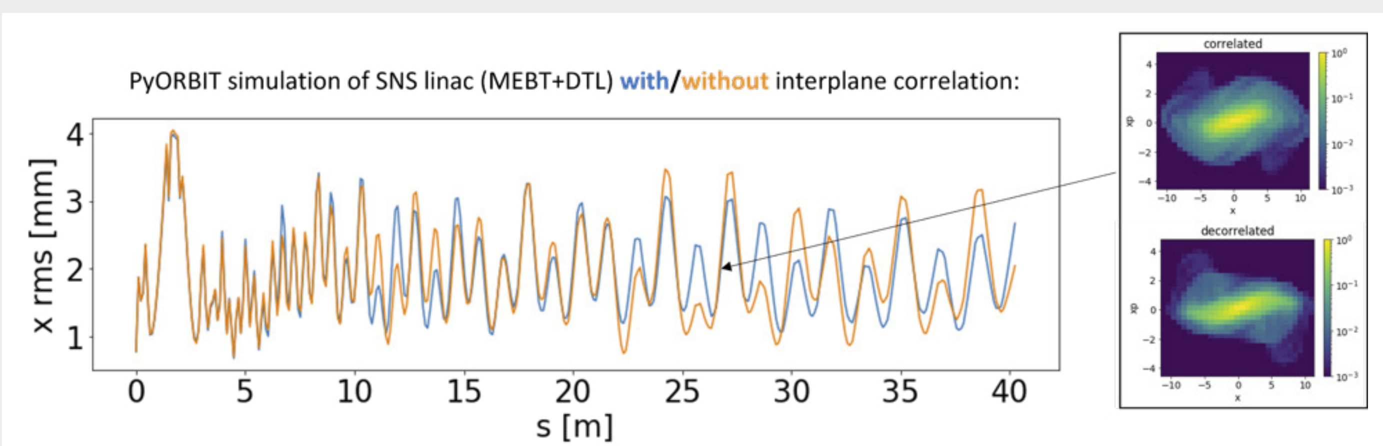

Figure 1: Evolution through the SNS MEBT and DTL of a 40 mA, fully-correlated bunch (blue) and a bunch that has been artificially decorrelated between the planes (orange). Figure is reproduced from [6].

Why 6D distributions?

Seeding self-consistent models with an accurate initial distribution is a universal challenge. Two options emerge: end-to-end simulation starting at the particle source, or reconstruction based on measurements. The latter is often preferred; although the end-to-end approach can yield fully-correlated distributions, modeling from source to medium energy can be challenging due to short length scales, high nonlinearity and lack of diagnostics.

The lack of full information about the beam distribution presents a fundamental limitation for model accuracy. Particle tracking requires the definition of the beam distribution in the 6D phase space f(x,x',y,y',z,z'). Typical diagnostics do not measure the 6D distribution directly, but instead resolve the largest correlations in the beam. At minimum, the rms emittance and Twiss parameters can be inferred. In the best case, measurement can return the 3 phase space projections f(x,x'), f(y,y') and f(z,z'). The 6D distribution can be reconstructed with no interplane correlation, f(x,x',y,y',z,z') = f(x,x') . f(y,y') . f(z,z'). This assumes uncoupled motion between the planes (e.g., a beam transported through ideal quadrupole optics). Space charge breaks this assumption.

Direct measurement of 6D beam distribution opens the possibility of seeding simulations with bunches that are both realistic and fully-correlated. The presence of correlations will influence downstream evolution. This is illustrated in Figure 1, using the SNS medium-energy (MEBT) and drift tube linac (DTL) as the test case. The bunch at the exit of the RFQ injector is artificially decorrelated between the planes. The difference eventually manifests in measurably different RMS beam sizes throughout the drift tube linac, as well as different tail orientations. These differences are significant because of the implications for halo extent. Gaussian approximations of halo extent are likely insufficient. As illustrated in Figure 2, halo particles often have very different phase space orientations than the beam core.

Measurement of beam distributions

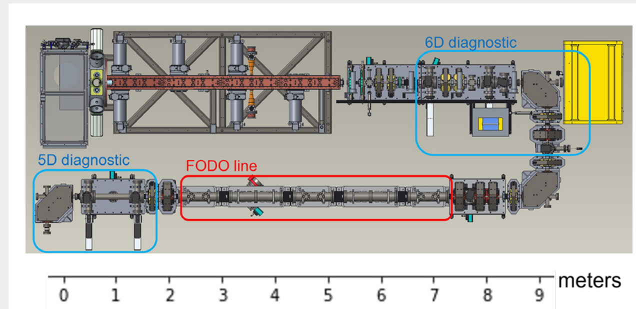

Figure 3. BTF layout, with phase space diagnostics and FODO line indicated.

Both full-and-direct measurement of the 6D beam distribution and accurate predictions at the loss level exceed the state of the art for linac systems. Work at the SNS BTF has focused on developing the 6D measurement and preparing the facility to support a halo-level benchmark of the output beam distributions.

The most recent configuration is shown in Figure 3. The BTF

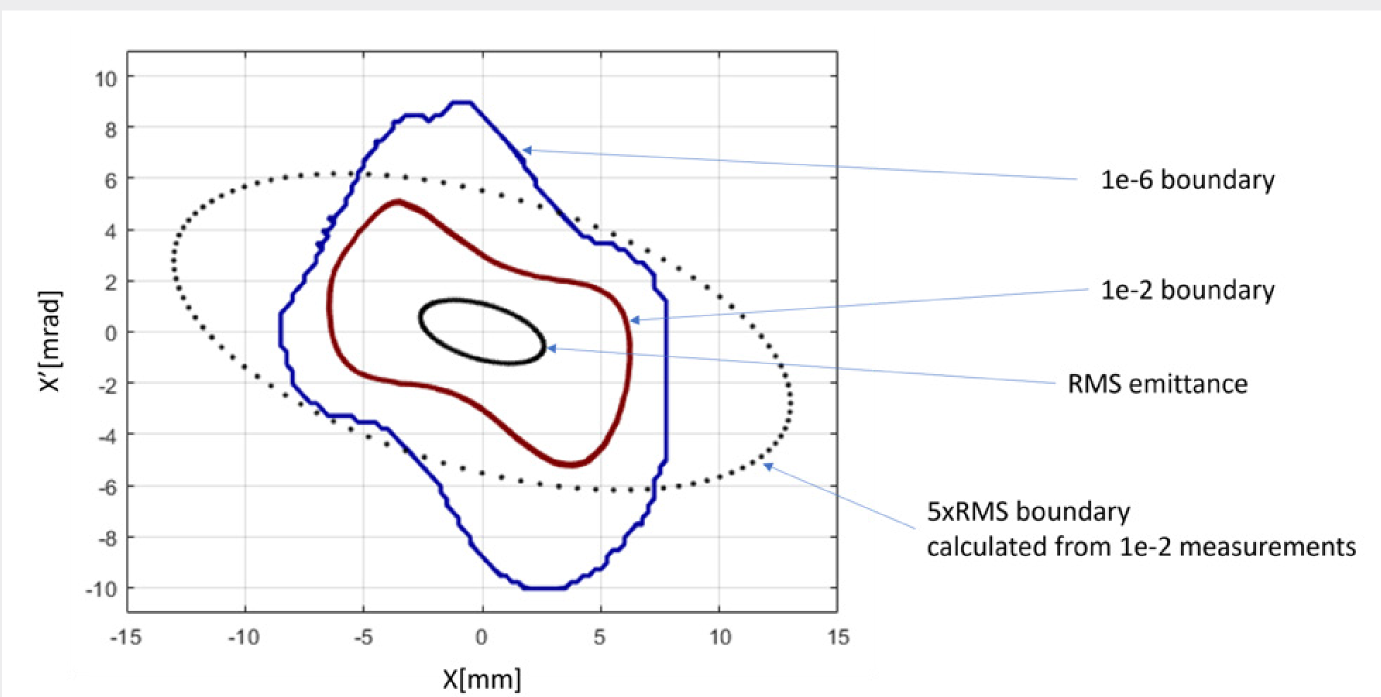

Figure 2: The tail/halo portion of the beam distribution lies in specific regions of the phase space, meaning the locations of maximal halo extent and possible scraping will not be well-predicted by a Gaussian/RMS assumption.

consists of a replica SNS injector (H- ion source, short electrostatic LEBT and 402.5 MHz RFQ) and a 2.5 MeV MEBT. The first 4 MEBT quads mimic the SNS design, but the rest of the beamline is significantly altered to support beam dynamics studies. The 6D diagnostic measures the distribution 1.3 meters downstream of the RFQ exit. Approximately 3 meters is dedicated to the 6D diagnostic, which is described in more detail below.

The 6D diagnostic is followed by a beamline extension, which consists of 4 matching quads, a permanent-magnet FODO line, and phase space diagnostic for the output distribution at the beamline end. The FODO line (red box in Figure 2) was added in 2018 to enable sufficient transport for halo growth [7]. It comprises 19 Halbach-style permanent magnet quadrupoles [8]. The permanent magnet approach was chosen to achieve a large phase advance in a compact and cost-effective footprint. The periodic structure resembles the periodic focusing in the DTL, with the crucial difference that there is no RF system for acceleration and/or longitudinal focusing. Therefore, hale growth in the BTF is mainly influenced by transverse dynamics.

All phase space measurements in the BTF use slit-based scan techniques (2 slits are used for 2D phase spaces, 3 slits for 3D, and so on). The dynamic range scales with dimensionality - sensitivity decreases by roughly one order of magnitude per slit inserted. Recent work at the test facility includes advancing measurement sensitivity, as illustrated in Figure 4.

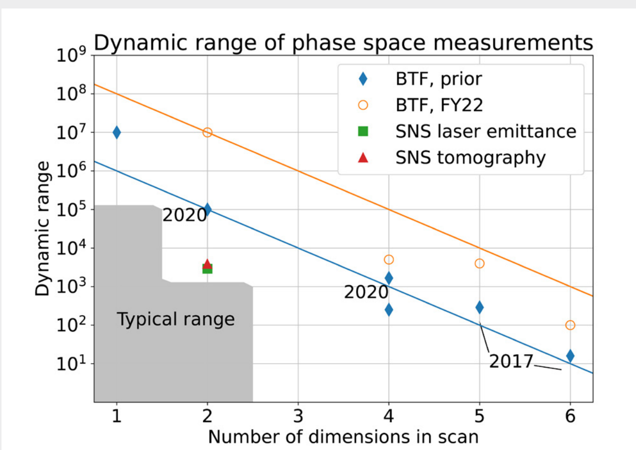

Figure 4. A history of dynamic range in BTF phase space measurements. The log-linear curve is drawn through the 2D point to illustrate the expected dependency of 1 order of magnitude per dimension.

Beam Halo

One challenge in verifying halo prediction is measuring low-level regions of the beam distribution. The on- part-per-million goal is motivated by the design SNS loss budget of <1 W/m losses [9]. To image distributions down to the 1 part-per-million level, a dynamic range of 10^6 is required. While this has been achieved in 1D profile measurements [11], a 1D view is not sufficient as halo may be "hidden" in the phase space. For complete characterization of halo, at minimum, the 2D phase space projections (e.g., f(x,x')) are necessary.

10^6 dynamic range in measurements of f(x,x') has been demonstrated at the BTF with a two-slit emittance diagnostic using optical charge collection from a scintillating screen [10]. This has a much lower background than a Faraday cup. Additionally, range stitching across two gains (exposures) is also applied. The implementation with H- ions, which neutralize rather than scatter off the slit edge, in combination with locating charge collection after the 90o dipole, is also critical for achieving low background.

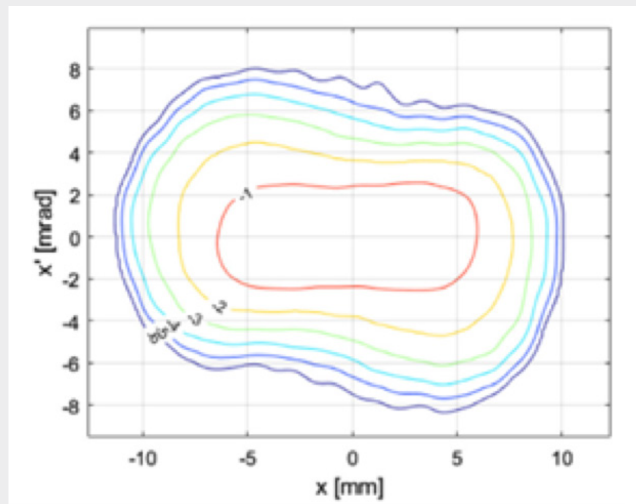

Figure 5. Horizontal phase space plot, f(x,x'), measured with 10^6 dynamic range.

6D distribution

The technique for 6D measurement at the BTF also uses a slit-scan approach [12]. The beam is masked by a sequence of thin (0.2 mm) slits that isolate the beam current density as a function of five of the six phase space coordinates, (x,x',y,y',z'). Downstream of the slits, a bunch shape monitor (BSM) [13] captures the profile in the final dimension, z. The BSM generates secondary electrons off a Tungsten wire, which are RF-deflected onto an imaging screen.

The challenge of full and direct 6D measurements is the large volume in high dimensional space, known as the "curse of dimensionality." For this reason, even low-resolution 6D measurements are time-intensive. A measurement of the 6D space on a grid of approximately 10 points per dimension requires 24 hours of continuous measurement at 5 Hz repetition rate rate.

A better strategy is to reduce the scan dimension, e.g. by using view screens if possible to measure one or two dimensions in a single shot. For example, measurement of the 5D distribution

∫ f(x,x',y,y',z') dz is possible using 3 slits and a viewscreen. For this configuration, scanning on a grid with 64 points/dimension requires 20 hours. Full 6D measurement using 2 axes of a viewscreen is not possible in the existing configuration, but will be implemented in the future. This has motivated development of a novel 2D BSM that can image the entire phase-energy distribution f(z,z') [14].

Characterization of the high-dimensional beam distribution at the BTF has revealed interesting correlations in the phase space that are omitted in typical reconstruction. The shape of the distribution at the measurement point is not well-described by analytic distributions such as Gaussian or Waterbag. Instead, the distribution has a hollowed core, seen very clearly the longitudinal distribution but also present in the transverse distribution. This is a "hidden" hollowing, as the fully projected views (in 1D and 2D) appear convex. The hollowed shape is only visible when isolating core particles.

Generally, hollowed spatial distributions are known to be an effect of non-linear focusing. The nonlinearity in this case is observed to be current-driven, consistent with expectations that 3D space charge drives correlations. Figure \ref{fig:hollowing} illustrates the core hollowing, with dependence on total charge as measured by the beam current transmitted through the RFQ.

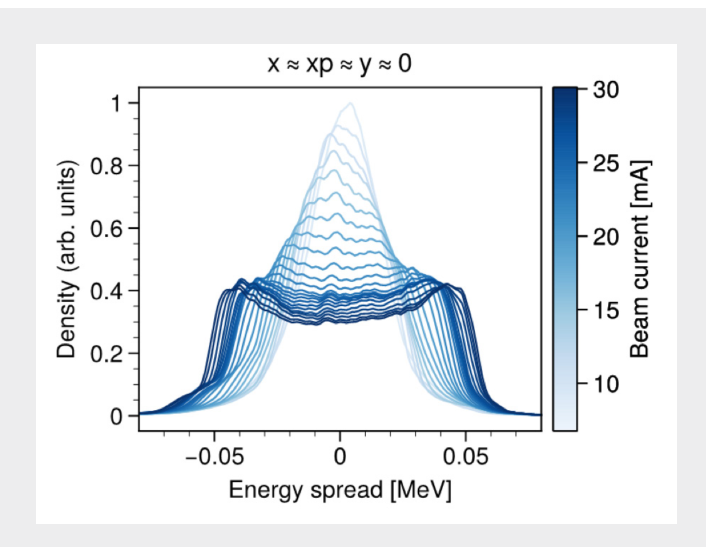

Figure 6. A slice of the beam energy distribution measured for a thin slice through the beam core in the phase coordinates x,x',y. The beam current is controlled by defocusing beam in the LEBT, such that it exceeds the RFQ acceptance.

Outlook

Accurate predictions at one part-per-million will enable model-assisted loss mitigation and pave the way for future 10+ MW facilities. Such facilities will provide intense neutrino and muon sources for high energy physics experiments, neutron sources for materials and energy sciences, and, in the future, accelerator driven systems for safer nuclear power and waste disposal.

For existing hadron accelerators, better predictive capability will lead to improved accelerator performance. Additionally, better understanding of basic beam physics such as halo formation and charge redistribution is broadly relevant to accelerators operating in the space charge regime.

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2022 Outstanding Doctoral Thesis Research in Beam Physics Award Recipient

An Interview with Ihar Lobach

Fermilab

Let's start with your thesis research: Can you give a brief description of the work, and its impact on the field?

In my dissertation, I carried out two experiments to study the statistical properties of the undulator radiation at the Fermilab Integrable Optics Test Accelerator (IOTA) storage ring. In the first experiment, we stored an electron bunch in IOTA with 1-3 billion electrons in it, and we detected the fundamental of the undulator radiation with an InGaAs p-i-n photodiode. We recorded the number of detected photons for about 11 thousand consecutive revolutions in IOTA (1.5 ms). Then, we calculated the variance of these 11 thousand numbers. The initial goal was to systematically study this variance as a function of various electron bunch parameters, such as charge, size, shape, divergence, etc. However, later we realized that we could reverse this procedure and infer some electron bunch parameters from the measured variance of the number of detected photons. Using this new technique, we were able to measure the small vertical emittance of the flat beam in IOTA, which was unresolvable by more conventional methods. Interestingly, the performance of this new method improves with smaller electron bunch sizes and shorter radiation wavelengths. Therefore, this technique may be particularly beneficial for the existing state-of-the-art and next-generation low-emittance high-brightness ultraviolet and x-ray synchrotron light sources.

In the second experiment, we stored a single electron in IOTA. By now, obtaining a single electron in IOTA is a standard and well-established procedure. The number of electrons in the ring can be inferred from the photocount rate of the synchrotron radiation. A single electron could be stored in IOTA for up to 2 hours at a time. We used a Single Photon Avalanche Diode (SPAD) to detect the individual undulator radiation photons (mostly from the second harmonic of the undulator radiation). Detections were observed once per about 300 IOTA revolutions, on average. With a single electron in the ring, all collective effects were eliminated (interference between the fields of different electrons), and we were able to study the quantum fluctuations of the number of detected photons in detail. Namely, we were searching for possible deviations from the expected Poissonian photon statistics.

Furthermore, we used the photon detection times, which were recorded by a picosecond event timer, to measure the synchrotron motion of a single electron. By comparing the measured synchrotron motion with a simulation, we were able to infer some dynamical parameters of the storage ring, such as the rms radiofrequency cavity phase jitter and the synchrotron motion period as a function of amplitude.

How did you become involved in accelerator research?

I was working on my undergraduate thesis at the Belarusian State University focused on the Parametric X-ray Radiation. It is a special kind of radiation, which is generated when an electron beam passes through a crystal at a certain angle to the crystal planes. At one point in this project, I had to learn how to prepare tight electron bunches and how to describe particle dynamics (in the focusing system and inside the crystal). Therefore, I applied for a summer internship in particle accelerator physics at Fermilab. It was during this internship that I started to like accelerator physics. I enjoyed the balance between theory and hands-on work. After this internship, I decided to apply for Ph.D. programs in accelerator physics, and just a year later started my Ph.D. at The University of Chicago.

What did you find most challenging during your PhD, technical or otherwise?

I had some short theoretical research projects during my undergrad, which very quickly resulted in small publications. When I started to work on my Ph.D., I quickly realized that my thesis project would be of much larger magnitude, and I would have to learn a lot of new theory and new simulation codes, build experimental apparatus and carry out many hands-on experiments before I would be able to publish anything. It was quite difficult mentally to not have any peer-reviewed publications during the first three years of my Ph.D. It felt like my work did not leave any footprint. However, during year four, all the collected data finally started to make sense and I was able to catch up and publish four peer-reviewed papers in just one year.

To sum up, at times it was difficult to stay motivated and focused because gratification (in the form of publications, conference talks and job offers) for Ph.D. work is very delayed, and, in fact, is not even guaranteed, since research projects often hit a roadblock that cannot be removed.

What advice do you have for graduate students in the field of accelerator physics?

My supervisor from my 2016 summer internship at Fermilab, Alexander Shemyakin, has a rule of thumb that whenever you have a detailed study plan for an experiment that accounts for every possible delay you can think of, you still need to multiply your estimate by pi to find the real time required to finish your experiment. That is, if you think your experiment is going to take one year from start to finish, it is probably going to take more than three years in real life. It is important to keep this in mind when planning your thesis project.

What are you working on now? Will you continue your earlier research, or start something new?

I could continue my earlier research at Fermilab after receiving my Ph.D. and I am sure I would love it. However, I decided to force myself to try something new and to work at another research group while I am still at an early stage of my career. Therefore, I accepted a postdoctoral position at the Advanced Photon Source (APS) at Argonne National Laboratory with a focus on applications of machine learning (ML) for accelerator tuning, control and anomaly detection. Argonne is treating me very well. I was recently promoted to a staff position. I am planning to continue the ML research, and to start contributing more to operations and to APS-Upgrade.

Tell us something interesting about yourself outside of work!

This is the hardest question of them all. Perhaps the first thing that comes to mind outside of work is that I like riding my bicycle and (to a lesser extent) jogging. It was very easy to reach the Lakefront Trail from the University of Chicago campus (in Hyde Park), which offered great views of the Chicago skyline and Lake Michigan. There were many nice trails near Fermilab as well. And, now, I really enjoy the Waterfall Glen Trail, which encircles Argonne National Lab. It even has some elevation gain and loss, which is very rare in the flat state of Illinois.

APS DPB Awards & Fellowships

2022 USPAS Prize Winners

Congratulations to the recipients of the 2022 USPAS Prize for Achievement in Accelerator Science and Technology:

Rama Calaga, Brookhaven National Laboratory

Citation: "For outstanding leadership bringing the crab cavities in hadron colliders from concept to reality and for the first demonstration of crabbing on a hadron beam." *Early-Career Award*

Geoffrey Krafft, Jefferson Lab

Citation: "For pioneering contributions to superconducting linear accelerators and radiation sources driven by them, and for his dedication in educating and mentoring the next generation of accelerator scientists."

Gennady Stupakov, SLAC National Accelerator Laboratory

Citation: "For comprehensive contributions to collective effects including coherent synchrotron radiation, invention of the echo-enabled harmonic generation scheme for external seeding of FELs, and his role as a teacher and a mentor in many schools and workshops."

IPAC 2022

Congratulations to the recipients of the IPAC 2022 Best Student Poster Prize:

Cristhian Gonzalez-Ortiz, Michigan State University

Proton intensity is increased at the Fermilab Accelerator Complex in order to provide more beam power to the neutrino and muon experiments. The current improvement plan (PIP-II) will require the Recycler Ring to store 50% more beam. Simulations have shown that the space charge tune shift at this new intensity will lead to the excitation of multiple resonance lines, specifically, third-order resonance lines. Dedicated normal and skew sextupoles have been installed in order to compensate for these resonances. Our work presented at IPAC 22 shows how we measured and calculated the Resonance Driving Terms (RDTs) for these lines. Furthermore, we demonstrated experimentally how to manipulate these RDTs and how we effectively compensated for each resonance.

Annika Gabriel, University of California & SLAC National Accelerator Laboratory

We have developed a new setup to measure the near-field of a nonlinear lithium niobate (LN) THz source in order to inform the design of improved THz-frequency accelerating structures. The setup was used to reconstruct the full temporal 3D THz near-field close to the LN emission face. Analysis of the results from this measurement will inform designs of novel structures for use in THz particle acceleration. THz-frequency accelerating structures could provide the accelerating gradients needed for next generation particle accelerators with compact, GV/m-scale devices. One of the most promising THz generation techniques for accelerator applications is optical rectification in LN using the tilted pulse front method. However, accelerator applications are limited by significant losses during transport of THz radiation from the generating nonlinear crystal to the acceleration structure. In addition, the spectral properties of high-field THz sources make it difficult to couple THz radiation into accelerating structures. A better understanding of the THz near-field source properties is necessary for the optimization of THz transport and coupling.

NAPAC 2022: TedPAC
APS Video Contest

1st Place: Hannah Hu
Development of an oxygen doping treatment for high Q and high gradient

Superconducting radio-frequency (SRF) cavities are a key technology for developing more efficient and higher energy particle accelerators. The introduction of impurities into the surface of niobium SRF cavities has been shown to greatly improve performance in terms of quality factor Q0 and accelerating gradient (Eacc). Recent work has highlighted the role of oxygen in driving performance features representative of nitrogen doped cavities. Most notably, we find that even in the absence of nitrogen, oxygen-doped cavities exhibit the phenomena of the anti-Q slope and the anomalous dip in resonant frequency before transition temperature. We show promising results of an oxygen doping treatment and evaluate it terms of the fundamental material properties, the thermal breakdown of the superconducting state and the impurity profile. Correlating these properties with performance features drives further insight into understanding underlying mechanisms which allow impurities such as O and N to enable high Q performance. These understandings enable the development of surface treatments to tailor and optimize the impurity profile for improved performance.

2nd Place: Loyd Waites

We are creating a compact machine that delivers current an order of magnitude higher than commercially available. In the process, we are experimentally demonstrating for the first time a new method for beam injection and how to exploit beam dynamics in the cyclotron. In addition, our research improves the tools of accelerator design by introducing modern computational techniques like machine learning.

The high current and small footprint provided by this beam enable new experiments, including a definitive sterile neutrino experiment designed to evaluate several anomalies. The high statistics further allow the IsoDAR experiment to evaluate models that include multiple sterile neutrinos, which have gained momentum based on the current global analyses. IsoDAR also simultaneously collects data to explore new parameters for axion dark matter. This is due to the nuclear excitations that occur within the target during bombardment. However, when using different targets it is possible to instead use the high current of IsoDAR to produce large amounts of medical isotopes, which can be used for therapies and diagnostic treatments. This can have a direct impact on the lives of hospital patients. Accelerators are the backbone of particle physics experiments and the nuclear medicine community. By shifting the paradigms of particle accelerator technology, we transform these fields, leading to discovery-level experiments and a highly increased yield of much-needed medical isotopes. With IsoDAR, there is a direct connection between the technology that can be used to understand our universe, and the technology which can be used to save people's lives.

NAPAC 2022:
Bronze Sponsor Award for Best Poster

Jiayang Yan

Plasma wakefield accelerators (PWFA) have demonstrated acceleration gradients of tens of GeV per meter. However, injection of high-quality electron beams in PWFA is a significant challenge. One method under investigation for injection of beams with desired properties is called beam-induced ionization injection (B-III). In this method, drive beam's field increases as its slice envelope oscillates to its minimum value due to the betatron oscillation, and releases impurity plasma electrons that are then injected to form a trailing beam.

This work investigates the ionization and trapping mechanism to control the injection process and beam quality. To investigate the formation of a trailing beam, electromagnetic field maps are simulated using the Particle-In-Cell (PIC) code, QuickPIC. Ionization and injection of electrons at any time step are then modelled by tracking the particles in the field map using an in-house code called eTracks.

Simulation results show that controlled ionization and injection processes can lead to the generation of a high-quality (ultrashort, femtosecond) trailing beam. Since the ionization process occurs due to the betatron oscillation of drive beam slices, an analytical expression has been derived to describe the envelope oscillation of those slices. As for the injection process, simulations reveal that only those electrons whose Hamiltonian go below a certain threshold can be trapped. This threshold value also behaves as a critical condition in the transverse phase space. Developing a formalism for the threshold Hamiltonian value or the critical condition in transverse phase space are subjects of future work. Future experiments at ATF and FACET II are also planned to demonstrate the generation of ultrashort electron beams in PWFA using B-III.

APS DPB Awards & Fellowships *(continued)*

Mathew J. Virgo Student Award

Liam Pocher
Optimizing the Discovery of Underlying Nonlinear Beam Dynamics

One of the Grand Challenges identified by the Office of High Energy Physics relates to the use of virtual particle accelerators for beam prediction and optimization. Useful virtual accelerators rely on efficient and effective methodologies grounded in theory, simulation and experiment. Typically, virtual accelerators are created using either computationally expensive simulations or black box methods such as machine learning. The underlying nonlinear dynamics governing beam evolution can be challenging to interpret and understand with such techniques. My presentation at NAPAC'22 arose from a cross-pollination of methods from the data-driven nonlinear dynamics community and the needs of the beam physics community.

My research uses an algorithm called Sparse Identification of Nonlinear Dynamical systems (SINDy), which has not previously been applied to beam physics. We believe the SINDy methodology promises to simplify the optimization of accelerator design and commissioning, particularly where space charge is important. At NAPAC'22, as an example, I showed how SINDy can be used to identify the underlying differential equations governing beam moment evolution. I compared discovered differential equations to theoretical predictions, results from the PIC code WARP, and prior work using machine learning. Finally, I proposed how the SINDy methodology SINDy can be used in the broader community's virtual and real experiments.

In Memoriam

We have collected the contributions for several of the accelerator and beam physics community members whom we have lost from the past few years since the pandemic. Here we present this information in their honor and to celebrate their contributions and lives.

Lee C. Teng (1926-2022)

Obituary written by Sandra Biedron

Lee Chang-Li Teng, a theoretical physicist who contributed to and designed many particle-accelerator-based projects around the globe passed away peacefully in hospice care on Friday morning 24th of June 2022. He was 95.

He was born in Beijing, China on the 5th of September 1926. He is the beloved husband of Nancy Lai-Shen (nee Huang) since their marriage in Chicago on the 21st of September 1961. He is the loving father of Dr. Michael Teng, loving father-in-law of Kim (nee Tran) Teng, and the loving grandfather of Isabella Teng. He is the loving uncle, cousin, colleague and friend to many.

Lee received his Bachelor's in Physics from the Fu-Jen University in Beijing in 1946. After emigrating to the United States in 1947, he received his Master's and Ph.D. also in physics from the University of Chicago in 1948 and 1951, respectively. He was the Ph.D. student of Gregor Wentzel and the title of his dissertation was "Polarization of Vector Mesons Produced in Nucleon-Nucleon Collisions." He worked for Nobel Laureate Enrico Fermi, who was also on his dissertation committee.

He held academic positions right after his Ph.D. at the University of Minnesota and at Wichita State University. He was recruited to Argonne National Laboratory and subsequently to Fermilab, where he held an array of scientific leadership positions. During this time, he was also the inaugural director of Taiwan's Synchrotron Radiation Research Center. He contributed to the design, operation, and upgrades of many particle accelerators for science including the zero-gradient synchrotron (Argonne), entire accelerator complex at Fermilab, the Taiwan Synchrotron, and the Advanced Photon Source (Argonne). He also designed and helped deliver the first proton therapy machine for treating cancer in the United States to Loma Linda, that has helped numerous patients battle and/or cure their cancer.

Lee also mentored early-career individuals and was always interested in educating his co-workers at all levels of training in particle accelerators. He gave lectures to the Argonne staff as well as at the United States Particle Accelerator School. He was recognized by his colleagues and received the designation of American Physical Society Fellow in 1957 and the Robert Wilson Prize of the American Physical Society in 2007. Robert Wilson was a close colleague to Lee and the principal architect of Fermilab.

Lee's smile was contagious that made it easy for him to make and keep friends as well as work globally.

Sergio Tazzari (1935-2020)

Reprinted from: https://w3.lnf.infn.it/in-ricordo-di-sergio-tazzari/

On 7 October, Prof. Sergio Tazzari, professor of General Physics at the Physics Department of the University of Rome "Tor Vergata" until 2006, of which he was also Director in the mid-1990s, passed away in Rome.

Sergio Tazzari was one of the world's leading experts in the field of linear and circular particle accelerators. His research activity began at the INFN Frascati National Laboratories, contributing to the creation of the ADONE accumulation ring, and continued as Head of the Accelerator Division and then as Director of the Laboratories in the period 1984-1989.

Of great impact for the Frascati Laboratory was its pioneering activity in the research on the Free Electron Laser (FEL) driven by superconducting accelerating cavities. In fact, the LISA project that he directed in the 90s, in addition to containing extremely innovative ideas for the time, such as for example the concept of recirculation and recovery of the energy of the electron beam, paved the way for further international collaborations that have led research groups from the University and INFN to participate as protagonists, and with national industry, in the impressive development of superconducting technology that joined DESY, Hamburg, with the TESLA project for the future lepton collider after LHC. TESLA, winning the competition with SLAC and KEK, became in 2004 ILC, the International Linear Collider. This enterprise, which has become global, has nonetheless left the legacy of the implementation of the great European XFEL project in Europe. Commissioned in 2017 in Hamburg, XFEL is the most powerful X-ray FEL in existence, which now serves a large community of researchers interested in the study of materials physics, molecular biology and many other industrial applications. In his continuous attention to the development of new technologies and the qualification of Italian industry, Sergio Tazzari, in addition to promoting the development of superconducting accelerator cavities, coordinated the effort of the consortium of Italian companies, Ansaldo, Europa Metalli and Zanon, which created for the INFN, at the end of the eighties, half of the more than 400 superconducting dipoles of the Hera project in Hamburg,

As a further example of his very high international reputation, Sergio Tazzari was chairman of the Machine Advisor Committee of the LHC, currently the largest accelerator in the world. He also contributed to the creation and development of the Elettra Sincrotron Research Center in Trieste, the Italian laboratory dedicated to the applications of synchrotron light, for which he was awarded the title of Elettra Fellow in 2014, also promoting the INFN-Elettra collaboration with the FABRE joint project.

Prof. Tazzari was also a passionate professor of Accelerator Physics, preparing generations of young people for a complex research activity, but full of perspectives and useful applications for society. He managed to pass on his passion for research to many people around him, who subsequently tried to further his visions and goals.

INFN colleagues remember him above all for his humanity, his kindness and courteous manners, such rare qualities in the world of work, which, for those who had the opportunity, made collaborating with him an infinite pleasure and a real honor.

Helmut Wiedemann (1938-2020)

Helmut Wiedemann was a Professor Emeritus of Applied Physics and of the Stanford Synchrotron Radiation Laboratory. He obtained his PhD from the University of Hamburg in 1971 and worked at DESY before becoming the assistant director of the 18 GeV PEP Storage Ring at SLAC in 1975.

His research interests included developments in theoretical and experimental accelerator physics, particle sources, linear accelerators, storage rings, and synchrotron radiation sources, with special interests in developing high brightness light sources at short pulse duration. Professor Wiedemann was a Fellow of the American Physical Society.

Thomas P. Wangler (1937-2021)

Reprinted from: https://losalamosreporter.com/2021/11/26/obituary-thomas-p-wangler-aug-2-1937-nov-20-2021/

Thomas (Tom) Patrick Wangler was born August 2, 1937 in Bay City Michigan to Frank and Florence Wangler. He earned his B.S. degree in Physics, in 1958 from Michigan State University, followed by a Ph.D. in Physics in 1964 from the University of Wisconsin.

He started his professional research career in high energy physics at the Argonne National Laboratory in Illinois where he worked from 1966 to 1979. After joining Los Alamos National Laboratory in 1979, he devoted his entire career in the field of Accelerator Physics. Tom is internationally known and recognized for his pioneering work in and foundational contributions to the development of high brightness particle linear accelerators. He became a Laboratory fellow in 1993. He was an excellent teacher and gained world-wide reputation for the accelerator physics courses he taught at various national and international universities such as Harvard University and Beijing University on behalf of the US Particle Accelerator School. Apart from his voluminous number of publications, he is best known for his book titled “RF Linear Accelerators” (John-Wiley) that has become the standard text-book across the graduate schools around the world.

Tom was an avid runner and enjoyed doing races. He competed in the Boston Marathon in 2005 at the age of 68, and the Marine Corps Marathon in 2007 at the age of 70, as well as many other marathons, half-marathons and triathlons. He was also an outdoorsman trekking the mountains of New Mexico and a polymath with interests in world history, religions of the world, science and natural history, constantly reading to learn more about topics that interested him. He taught himself how to sail in graduate school, by getting in a boat during a sailing race and just following the other boats. He was known as a great traveling companion by co-workers because of his ability to find excellent restaurants in any city. He was also a sports fan cheering for his beloved Michigan State Spartans, as well as the Chicago Bulls, the Chicago Bears and the Houston Astros.

Tom loved his family and music. He was an exemplary father to his children. He lived for over 40 years in Los Alamos. He spent many an hour coaching soccer (a sport he never played and had to learn from books) and traveling with his wife and children. He enjoyed playing the banjo and singing for his grandchildren. He was an active member in the Catholic church and enjoyed singing in the choir for several years during his retirement.

Tom died on November 20th in his home with family due to complications of Alzheimer’s disease. He was preceded in death by his parents and his nephew, Tom Wangler. He is survived by his wife Julia of 46 years, his son Michael his daughter Annie Blank and her husband Andrew, 5 grandchildren Samuel and Claire Wangler and Marissa, Devin and Isaac Blank, his brother Frank and his wife Kim, his nephew Steve and Steve’s family, and nieces, Lynde and Jessica. The family would like to thank Damian Tapia of Egis for his excellent and caring home health care.

A funeral mass in celebration of his life will be held at Immaculate Heart of Mary Church on December 11 at 10 am. In lieu of flowers, donations may be made to Immaculate Heart of Mary Church, Michigan State University, or a charity of your choice.

Alan Jackson (passed 2020)

Reprinted from: https://als.lbl.gov/in-memoriam-alan-jackson-retired-accelerator-physicist/

On September 28, 2020, retired Berkeley Lab accelerator physicist Alan Jackson died of cardiac arrest while visiting family in the UK. A longtime leader in the accelerator physics community, Alan had a hand in building synchrotrons around the world. He began his career in 1968 at the world’s first dedicated x-ray synchrotron light facility, the Synchrotron Radiation Source (SRS) in Daresbury, UK. In 1985, he came to Berkeley Lab, where we remember him best for heading the accelerator physics group of the ALS during its design, construction, and early years of operation.

“He was one of the founding fathers of the ALS,” recalled Howard Padmore, ALS photon science development lead. Other colleagues had a ready list of his accomplishments and contributions. “Alan had a major impact on the ALS in the design, construction, commissioning, and early operations phases of the ALS,” said David

Robin, now director of the ALS Upgrade Project. “He encouraged the accelerator team to push the boundaries of the accelerator to see what was possible. Almost everything we tried was new and we learned so much,” he added.

Alan’s work was at the very root of the ALS in the mid-1980s—pioneering the third generation of synchrotron light sources—and he played a key role in the team effort that led to its smooth commissioning and operation. Fernando Sannibale, current ALS deputy for accelerator operations, explained, “Following up on an original idea by Gaetano Vignola, Alan refined and implemented the novel triple-bend-achromat lattice at the ALS.” This type of “lattice,” or array of magnets that steer the electron beam in its orbit, was later adopted for a number of high-brightness synchrotron light sources worldwide in the energy range of the ALS.

The intricacies of designing such a machine were compounded by the realities of repurposing a historical building atop a hill and near a fault line, but the team persevered, and the ALS achieved first light in 1993. Alan’s expertise in accelerator design continued to prove essential as the ALS moved to expand its portfolio. Together with Werner Joho of Paul Scherrer Institute, he had another idea that would greatly extend the user service at the ALS: installing superconducting bend magnets. The triple-bend achromats were a series of three magnets, the magnets on either end mirroring each other. This symmetrical arrangement enabled the center magnet to be replaced without undesirable effects, so superconducting dipoles were substituted in the center position in three sectors of the storage ring. The three superbends were commissioned in Fall 2001 and have provided light for Nobel-prize-winning work and world-leading programs in structural biology, high-pressure diffraction, microdiffraction, chemical crystallography, and tomography ever since.

Alan served as deputy director of the Accelerator and Fusion Research Division and as head of its Superconducting Magnet Program before his retirement from the Lab in 2008. His experience made him the natural candidate to lead the development of the Australian Synchrotron. Impressed with their visit to Berkeley Lab, a senior delegation from Australia asked Alan to be the technical director for their design task group. “Alan was highly regarded in his field,” wrote Dean Morris, head of operations for the Australian Synchrotron. Alan’s four years there helped the project quickly design a storage ring and achieve first light in a relatively short period of time. “He made a lot of friends when he was in Australia and will be sorely missed by many,” said Morris.

Former Director of the Accelerator and Fusion Research Division Bill Barletta encapsulated Alan’s personable and effective management style, saying, “He had superb relations with the technical and administrative staff and was an ideal source of ‘ground truth’ when those who knew firsthand would generally clam up to ‘the management.’” Robin agreed, saying, “Alan was a dynamic and supportive leader. As a young accelerator physicist, I remember those first few years of operation being tremendously exciting, fun, and fruitful.”

The global accelerator community mourns not just the loss of Alan’s expertise, but also his friendship and joie de vivre. Besides his distinguished contributions to accelerator physics, Alan greatly enjoyed life away from work and was an avid sailor, sports car enthusiast, and center of a wide network of friendship. Padmore said, “He was a larger-than-life person who lived life to the fullest and was the life and soul of ALS in its early years.” Kem Robinson, retired senior physicist and former head of the Lab’s Engineering Division and Project Management Office, concluded, “Alan wasn’t afraid to take on whatever needed to be done for the greater good. Yes, he will be missed.”

Mathew John Virgo (1978-2022)

Reprinted from: https://www.legacy.com/us/obituaries/qctimes/name/mathew-virgo-obituary?id=33140202

Mathew John Virgo passed away suddenly at the Chicago home he shared with his loving wife Sharon on the evening of February 10, 2022.

Mathew was born on June 20, 1978, and grew up in Ithaca, New York and Bettendorf, Iowa. He earned his B.S. in Computer Engineering at Iowa State University, then his M.S. and Ph.D. in Electrical Engineering at the University of Maryland. He spent his entire 18-year professional career at Argonne National Laboratory, where he made lasting contributions to numerous projects in Photon Sciences and, more importantly, the lives of his colleagues.

Mathew was a lifelong learner who would wholeheartedly dive into his current topic of interest, ranging from computer engineering and particle physics to music composition and indie bands. He was equally comfortable doing research with colleagues in a scientific laboratory or by himself at a White Stripes concert.

Always with a taste for what's good in life, Matt spent considerable time searching for the perfect shot of espresso and matching sweet treat. Not that he would step behind the bar or into the kitchen himself-numerous baristas and bakers around Chicago benefited from his consistent support and honest critiques.

Mathew's friends and family will remember him as a genuine, kind soul who was always willing to give a helping hand but shunned attention on himself. He would try to learn something from everyone he met and was always willing to insert his sharp wit and self-deprecating sense of humor.

Mathew is survived by his beloved wife Sharon, his parents Richard and Dorna Virgo, brother Anthony (Anne) of Boulder, CO, and sister Jenna (Rachel) of New Orleans, several aunts, uncles, nieces, and nephews, and his Pug Franklin. Mathew will be profoundly missed by his family, friends, and coworkers.

While Mathew would never want to be celebrated, he lived a life worth celebrating. A memorial service is planned for June 20, 2022 in Ithaca, New York at Taughannock Falls State Park.

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(301) 209-3200
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1 Research Road
Ridge, NY 11961-2701
(631) 591-4000

Office of Public Affairs
National Press Building
529 14th St NW, Suite 1050
Washington, DC 20045-2001
(202) 662-8700
(202) 662-8711 FAX

Copy Editor:
Joseph McClain

Layout Editor:
Tyler Small (The Field's Five)