Image: Experimental setup for successfully demonstrating the conduction-linked cooling of a single SRF cavity. See page 22 for details. **Photo Credit:** Marty Murphy

APS DPB NEWS

APS Division of Physics of Beams Annual Newsletter ////////// **2019**

In this Issue:

Disclaimer: The articles and opinion pieces found in this issue of the APS DPB Newsletter are not peer refereed and represent solely the views of the authors and not necessarily the views of the APS.

Dear Readers,

Welcome to the 16th APS DPB Newsletter! This year, we highlight recent research and innovations in our field not only nationally but internationally, and we follow up on the latest updates in our community.

In this issue, we present major news on the construction and commissioning period of the Facility for Rare Isotope Beams, the status of the HL-LHC and the advancing plans for the next big collider at CERN. Moreover, you will find future trends in electron linacs for industrial and medical applications, and the recent major step toward a compact superconducting accelerator for industrial applications at Fermilab. You will also find noteworthy details about the International Particle Accelerator Conference 2019 (IPAC'19) held in Melbourne and the North American Particle Accelerator Conference 2019 (NAPAC'19) held in Lansing, MI.

Furthermore, you will get important information about the Accelerator Science & Engineering Traineeship Program at Michigan State University, and we have an exciting read about the evolution of the U.S. Particle Accelerator School and its status and future directions.

You will also find 2019 APS DPB Awards & Fellowships, our interview with the DPB Dissertation Award Recipient, important dates in 2020 and obituaries of members in our community.

We would like to thank to all of our authors for their valuable contributions and 2019 APS DPB Executive Committee Members for their endless support.

Please let us know if you have suggestions for an article or any comments, questions or concerns, and don't hesitate to get in touch if you would like to share your research in the next issue.

Enjoy,

Nihan Sipahi
APS DPB Newsletter Co-Editor
and Early Career Member-at-Large
PhD, Colorado State University
nihan.sipahi18@alumni.colostate.edu
(970) 980-8904

Martina Martinello
APS DPB Newsletter Co-Editor
and Early Career Member-at-Large
PhD, Fermi National Accelerator Laboratory
mmartine@fnal.gov
(630) 840-6753

Meet the 2019 Executive Committee

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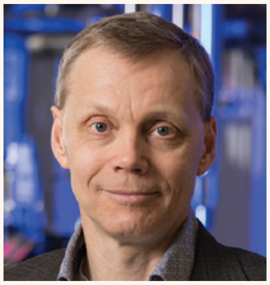

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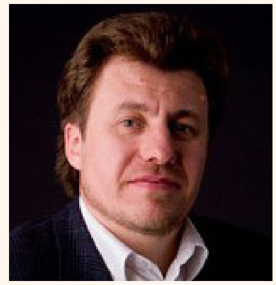

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From the Chair

Michiko Minty *Brookhaven National Laboratory*

The DPB Executive Committee consists of 14 elected members (four Officers—chair, chair-elect, vice chair and secretary-treasurer—the past chair, the Division Councilor, six Members-at-Large and two Early Career Members-at-Large) augmented by two members of the Particle Accelerator Conference Organizing Committee (the conference chair and the conference NPSS/IEEE representative) and chairs of appointed DPB committees. The latter comprises the DPB Program Committee, Fellowship Committee, Publications Committee, Nominating Committee and the following ad hoc committees: the Education, Outreach and Diversity Committee; the Doctoral Research Award Committee; and the Wilson Prize Committee. Together, the DPB Executive Committee works on behalf of the entire DPB community in supporting the objectives of the division, which include promoting research and development in the physics and technology of accelerators and beams, promoting applications of the science of beams, encouraging and enabling communication through publications and conference sponsorship, promoting education in the physics and technology of accelerators and beams, and enhancing the professional standing of members through coordination of awards, prizes and fellowships.

Some highlights from this year's activities include granting fellowships to DPB members and bestowing prizes and awards. The new APS Fellows nominated in 2019 by the DPB under the direction of DPB Fellowship Committee chair Sarah Cousineau are Matthias Liepe (Cornell University), Ji Qiang (LBNL), Alexander Romanenko (FNAL), Frank Schmidt (CERN) and Nikolay Vinokurov (Budker Institute of Nuclear Physics). Chaired by W. Barletta (MIT), the joint DPB/DPF Robert R. Wilson Prize for Achievement in the Physics of Particle Accelerators was awarded at the 2019 April APS meeting to Toshiki Tajima (University of California, Irvine) "for the invention and leading the first realization of laser wakefield acceleration, which opened the way to compact acceleration applications such as ultrafast radiolysis, brilliant x-rays, intra-operative radiation therapy, wakefield beam dump, and high energy cosmic acceleration.": Chaired by Rami Kishek (University of Maryland), this year's Outstanding Doctoral Thesis Research in Beam Physics Award was granted to Giada Cantano of Lund University "for pioneering work on surface-plasmon enhanced radiation sources in ultrashort laser-grating interaction at relativistically strong intensities, which led to the demonstration of a source of beamed, quasi-collinear high charge multi-MeV electron bunches and attosecond XUV photon bursts."

Another great accomplishment led by this year's DPB EC vice-chair Sarah Cousineau, working together with Jeanette Russo and Sarah Monk of APS and Susan Winchester of the US Particle Accelerator School, was the establishment of student travel scholarships. Two scholarships were awarded for the June, 2019 USPAS and 9 scholarships have been awarded for the January, 2020 USPAS.

This year also marked a first APS DPB Exceptional Service Award, presented at NAPAC'19 to Stan Schriber, DPB secretary/treasurer from 2008-2017. The award citation was: "In recognition and appreciation from the Division of Physics of Beams for outstanding service to the Society and to the entire field of accelerators and beams." We thank Stan for his continuing strong support and guidance and thank both Stan and Marion White, present DPB secretary/treasurer, for their leadership and dedication which this year included also generation of detailed documentation of DPB activities to assist EC succession.

The division was active this year in organizing various conferences, conference events and DPB membership drives. At the 2019 April APS meeting, the division coordinated with DPF and DNP to host six invited sessions and one contributed session, and provided representation at the DPF Townhall Meeting dedicated to planning for the next Snowmass conference. At NAPAC'19, which DPB sponsors, the EC held its annual regular meeting, annual business session, hosted a DPB student breakfast and awards session, and participated in conference tutorials. Members of the DPB EC chair line also attended the APS-sponsored Leadership Convocation in Washington, DC, in Jan. 2019 to learn of broader issues and initiatives of the APS.

Looking forward, in addition to the DPB's conventional roles, the DPB EC is working on establishing new scholarships for student attendance at APS meetings, is organizing DPB's contributions to the next Snowmass Conference, and is coordinating with APS to further recognize accelerator scientists through additional awards.

Next year's APS DPB Executive Committee chair line is composed of Sergei Nagaitsev of FNAL (chair), Sarah Cousineau of ORNL (chair-elect) and newly elected Frank Zimmermann of CERN (vice-chair). Other new elected members of the EC are new Members-at-Large Todd Satogata of JLAB and Georg Hoffstaetter of Cornell University and Early Career Member-at-Large Nicholas Evans of ORNL . We bid adieu and thank outgoing elected members for their dedication and contributions to the DPB EC: past-chair Vladimir Shiltsev of FNAL, Members-at-Large Wim Leemans of DESY and Sasha Zholents of ANL, and Early Career Member Nihan Sipahi of Colorado State, lead editor of this year's DPB Newsletter.

From the Secretary Treasurer

Marion White *Argonne National Laboratory*

DPB is performing very well as an APS Division. Our members are interacting with other professional societies and government organizations involved in accelerator-related activities. Financially, the DPB is doing well, but we continue to see that while overall APS membership is increasing, the DPB membership remains nearly constant. Membership is a serious concern because if our membership is too low, DPB could cease to be an APS Division. Consider encouraging 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 has provided funds to support the annual newsletter, the APS International Research Travel Award Program and a student support program that funded students to attend IPAC'19, NAPAC'19 and—starting this year—USPAS. DPB income is mostly derived from conferences and is generally spent on activities like these.

The EC has held three GoToMeeting phone calls this year and held an in-person meeting at NAPAC'19. We are maintaining updates to our APS-DPB website and track action items from our meetings.

The 2019 election was successfully held, despite being very late. We tied last year's all-time-best voting record with 401 of our members voting!

The Tenth International Particle Accelerator Conference (IPAC'19)

Mark Boland and Michiko Minty
Canadian Light Source and Brookhaven National Laboratory

The 10th International Particle Accelerator Conference (IPAC'19) was held in Melbourne, Australia, May 19–24, 2019. Hosted by the Australian Nuclear Science and Technology Organization (ANSTO), the event attracted more than 1,100 accelerator professionals from 42 countries, plus 72 industrial exhibitors. The scientific program included 85 scientific talks and over 1,400 poster presentations. This year, for the first time in the IPAC conference series, the opening and closing sessions were live-streamed to allow the widest possible participation via remote access to these key sessions.

In the opening plenary session, S. Sheehy from the University of Melbourne described successes of particle accelerators and selected future challenges, M. Ferrario of INFN/LNF presented on prospects for applying advanced accelerator technologies to next-generation scientific user facilities. S. Igarashi of KEK presented on achieved performance and future prospects for higher beam power at J-PARC, D. Kostin of DESY discussed lessons learned from SRF operations at the XFEL, and L. Rossi presented on progress with the high luminosity LHC program at CERN. The closing session featured H. Chapman of DESY presenting on faster, smaller and brighter X-ray imaging, L. Gizzi of INO-CNR discussing lasers for novel accelerators, and D. Wang of SINAP presenting an overview of light source developments in Asia.

The interim sessions, with invited and contributed talks as well as poster sessions, spanned the entire breadth of accelerator research and development in the physics and technology of accelerators and beams. Reports on mature hadron facilities were balanced by talks on photon sources and electron accelerators. Presentations on the most recently commissioned accelerators were a particular highlight, with presentations on Japan's SuperKEKB collider, Korea's PAL-XFEL free-electron laser and Sweden's MAX IV light source.

In a dedicated ACFA awards ceremony, prizes were awarded in recognition of outstanding work in the field of accelerators. Professor V.G. Vaccaro of the University of Naples received the Xie Jialin Prize for a recent, significant, original contribution to the field of accelerators. DPB's past chair Professor V. Shiltsev of FNAL received the Nishikawa Tetsuji Prize for a recent, significant and original contribution to the field of accelerators awarded. An early-career scientist, Dr. Xueqing Yan of Peking University received the Hongil Kim Prize. An even younger accelerator physicist, J. Macarthur of Stanford University, received the Mark Oliphant Prize for the quality of work and promise for the future. And two Best Student Poster Prizes were awarded to D. Bafia of FNAL/IIT and N. Samadi, CLS University of Saskatchewan.

"In Unity" was chosen as the theme for IPAC'19. Prevalent, beautiful artwork commissioned from Torres Strait islander Kelly Saylor symbolized the coming together of the particle-accelerator community. A conference Welcome to Country performed by a local aboriginal elder, followed by a traditional dance and digeridoo performance by an aboriginal family group during the conference banquet were nice added cultural experiences. Also appreciated by all was the banquet feature speaker Professor J. Seymour of James Cook University, who presented on his area of specialization—Australia's venomous species—which elicited equal parts humour and fear.

The next International Particle Accelerator Conference will take place in Caen, France May 10-15, 2020. As in the past, student participation is most welcome, and fostered by student grants sponsored by the APS in the Americas, ANTSO in Asia, and multiple sponsors in Europe (see website for details).

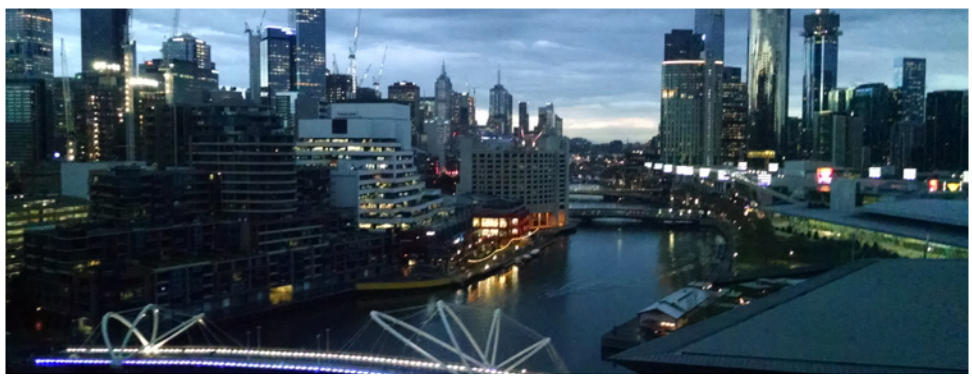

Photo Credits: Nick Harrison and Michiko Minty

Many Early-Career Accelerator Scientists and Engineers Participated in North American Particle Accelerator Conference in Michigan

Yoshishige Yamazaki *NAPAC'19 Conference Chair, MSU*

The 2019 North American Particle Accelerator Conference (NAPAC'19) took place in Lansing , Michigan, September 1–6, 2019. The NAPAC series of conferences covers the entire spectrum of accelerator science and technology topics like the IPAC series, but are regional (participants, however, are not limited to those from the region) and are more focused on early career scientists and engineers, including students and research associates (postdoctoral fellows). The NAPAC series takes place every three years to increase participants' opportunities to attend conferences twice, since they may have little opportunity to fly abroad, while the IPAC series takes place only every three years in North America.

Co-sponsored by the Institute of Electrical and Electronics Engineers (IEEE) and the American Physical Society (APS), NAPAC'19 was hosted by Michigan State University (MSU). At MSU, the Facility for Rare Isotope Beams (FRIB)—with the world's highest heavy-ion beam power of 400 kW—is under construction, having already started its beam commissioning and having most cryomodules completed. The site tour was thus one of the highlighted events at the conference. The opening plenary talk was by T. Glasmacher (FRIB/MSU) on the motivation, status and technical challenges of the FRIB project. This was followed by A. Seryi's talk on electron-ion collider design, which is for one of the most promising nuclear physics projects just after FRIB. In contrast, the closing plenary session was dedicated to the application or spin-off of the accelerator technology; quantum computers; future synchrotron radiation source and radioisotopes used in medical imaging.

In line with the NAPAC purpose mentioned above, many events were planned for students. First, the student poster session on Sunday afternoon was very exciting, with 65 total posters and stimulating discussions and conversations. Among them, four posters were awarded which highlighted accelerator technology developments presented at NAPAC'19 and showed recent trends and developments:

- GaAs-based photocathodes with Cs, Sb, and O_2 (J. Bae, Cornell).
- Sub-femtosecond x-ray pulses measurement (S. Li, SLAC).
- Laser-driven semiconductor pulse chopper with 10 ns, MW (J. Picard, MIT).
- Nb_3Sn SRF cavity (U. Pudasaini, College of William & Mary).

Free breakfast for students every morning provided them with the opportunity to have conversation with experts whose organization sponsored the breakfast. Three short courses on Sunday and four tutorials from Tuesday to Friday had a deep-dive nature, being very useful for students and for early-career scientists and engineers alike.

In addition to these short courses and tutorials, 47 exciting, invited talks—well balanced among eight main classifications—were presented together with 75 contributed orals and 272 posters. Approximately 400 attendees were brought together.

A Women in Science and Engineering (WISE) event on Wednesday attracted 110 attendants, and the five panelists had interesting things to discuss. The audience was engaged. The Louis Costrell Honorary Awards Session was for the four student poster prizes as well as the traditional award ceremony for the APS Division of Physics of Beams Outstanding Doctoral Thesis Award, which went to G. Cantono (for research at CEA Saclay). U.S. Particle Accelerator School Awards went to F. Zimmermann (CERN) and C. Geddes (Lawrence Berkeley National Laboratory), and the IEEE Nuclear and Plasma Science Society (NPSS) Particle Accelerator Science and Technology (PAST) Doctoral Student Award went to D. Cesar (for research at UCLA). The IEEE NPSS PAST Award went to P. Craievich (PSI), and J. R. Cary (Tech-X and U. Colorado). The APS DPB Outstanding Service Award and Physical Review Accelerator and Beams Robert H. Siemann Award were to S. Schriber (MSU, Emeritus).

The next NAPAC will take place in New Mexico to be hosted by Los Alamos National Laboratory in 2022.

FRIB Construction and Beam Commissioning Updates

Jie Wei *Michigan State University*

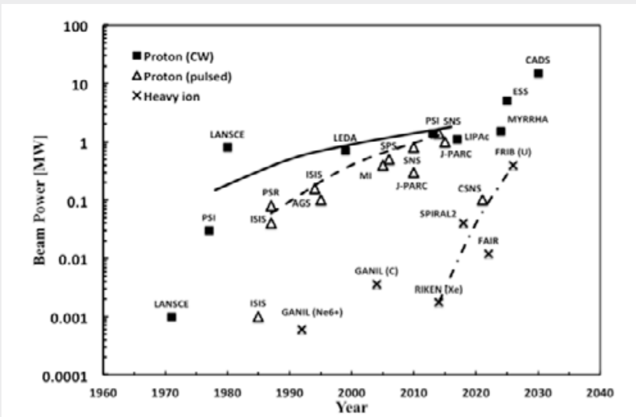

Figure 1. Evolution of hadron accelerator beam power. The three curves indicate the growth of power of continuous-wave proton beams, pulsed proton beams, and heavy ion beams, respectively.

On During the past few decades, accelerator-based facilities such as the Spallation Neutron Source, the Japan Particle Accelerator Research Complex, the Swiss SNS at Paul Scherrer Institute and the Los Alamos Neutron Science Center have advanced the frontier of proton beam power to the 1 MW level, as shown in Fig. 1. The Facility for Rare Isotope Beams (FRIB) is designed to advance the frontier of heavy-ion beam power by more than two orders of magnitude to 400 kW [1].

In August 2014, the U.S. Department of Energy's Office of Science approved Critical Decision-3b (approve start of technical construction) for the FRIB project. The total project cost for FRIB is \$730 million, of which \$635.5 million is provided by DOE and \$94.5 million is provided by Michigan State University (MSU). The superconducting RF (SRF) driver linac is designed to accelerate all stable ions including uranium to energies above 200 MeV/u primarily with 46 cryomodules (CMs) containing 104 quarter-wave resonators (QWR) and 220 half-wave resonators (HWR). The project will be completed by 2022. When completed, FRIB will provide access to completely uncharted territory at the limits of nuclear stability, revolutionizing our understanding of the structure of nuclei as well as the origin of the elements and related astrophysical processes.

Three years after the start of technical construction, the FRIB project entered phased commissioning with the heavy-ion beams starting with the room-temperature front end followed by the first segment (LS1) of the SRF linac, as shown in Table 1. With the newly commissioned helium refrigeration system supplying liquid helium to the QWR and solenoids, heavy ion beams including neon, argon, krypton and xenon were accelerated to the charge stripper location above 20 MeV/u with the 15 cryomodules of LS1 containing 104 QWRs of β=0.041 and β=0.085, and 39 superconducting (SC) solenoids. Even at this intermediate stage, the FRIB accelerator has already become the world's highest energy continuous-wave (CW) hadron linac (Fig. 2) [2].

The main purpose of front-end commissioning in 2017, within the accelerator readiness phase 1, was to integrate room-temperature accelerator systems together with the newly built civil infrastructure including electricity and water (Fig. 3). Emphases were on hazard

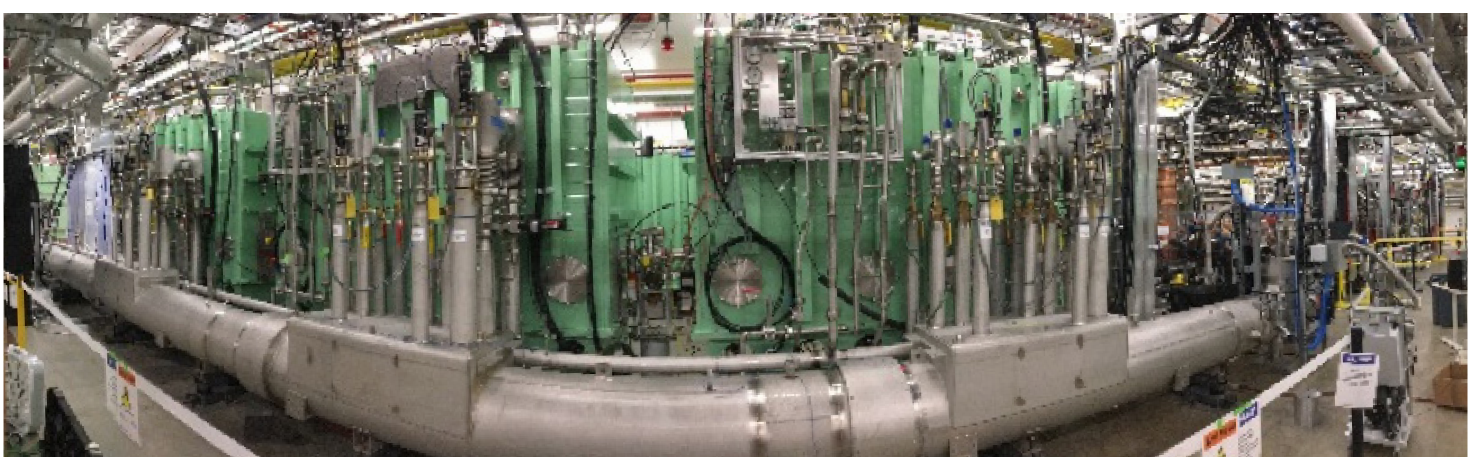

Figure 2. Aerial view inside the FRIB accelerator tunnel during the ARR3 beam commissioning in March 2019 shown with the cryogenic distribution in the foreground, cryomodules behind, and the front end to the right.

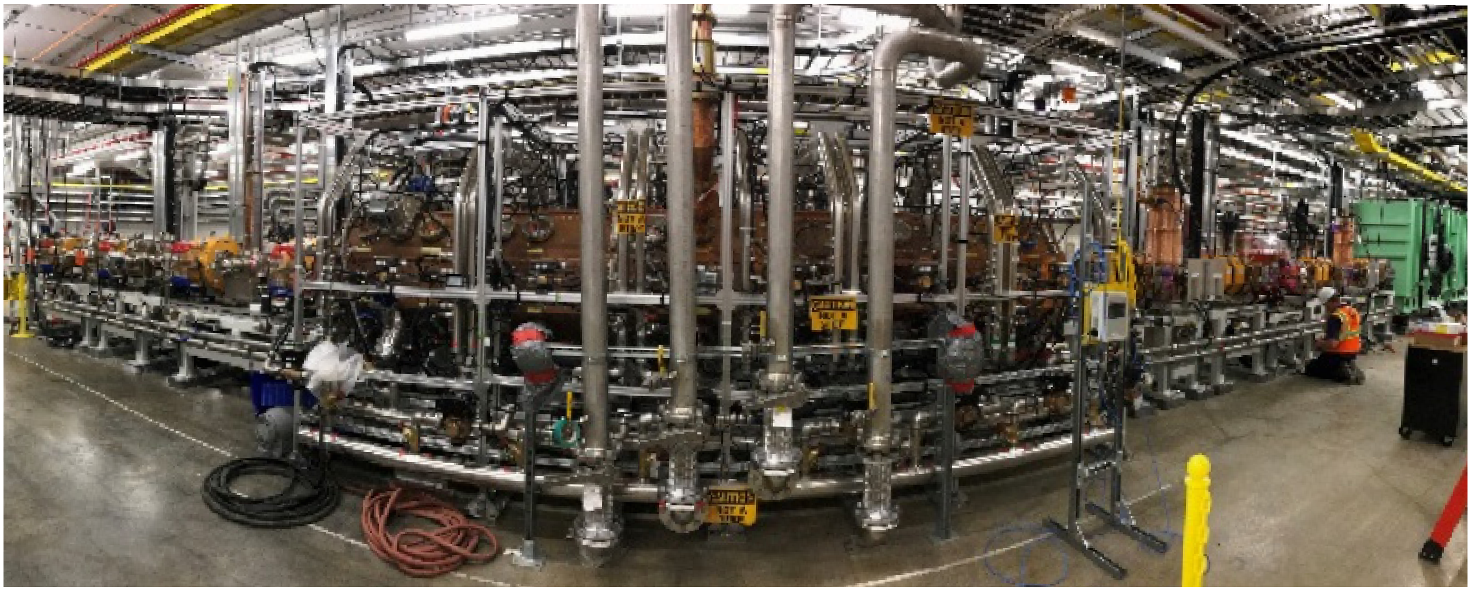

Figure 3. Aerial view of the room temperature lower LEBT including the 80.5 MHz RFQ during the front-end beam commissioning (ARR1) in 2017. The downstream SRF section is to the right.

mitigation for personnel safety (electrical hazard from the high voltage platform and radiation hazard from the source plasma) and conduct of operations. The ARR1 commissioning goals were promptly achieved with both argon and krypton beams produced from the ion source, transported through the low energy beam transport (LEBT) with pre-bunching, and accelerated by the RFQ to beam energy of 0.5 MeV/u with full design transmission efficiency of about 85%.

The main purpose of ARR2 commissioning in 2018 was to perform integrated tests of nearly all accelerator systems with emphasis on cryogenics and cryomodules. After establishing the oxygen deficiency hazard control system, we first started the commissioning of the FRIB cryoplant at 4 K (Fig. 4), followed by the commissioning of the cryo-distribution and the cool down of the cryomodules. The tunnel access control system is activated for radiation hazard mitigation before we proceed with RF conditioning of the SRF resonators. As cryomodules have been 100% tested at multiple stages (cavity/coupler/solenoid individual tests and cryomodule bunker tests), the conditioning in tunnel proceeded rapidly. The ARR2 commissioning goals were again promptly achieved with both argon and krypton beams from the front end accelerated by the three cryomodules to beam energies above 2 MeV/u with 100% transmission efficiency.

ARR3 commissioning in 2019 aimed at accelerating the beams of various ion species (neon, argon, krypton and xenon) above 20 MeV/u energy passing the charge stripper. Three β=0.041 accelerating cryomodules, eleven β=0.085 accelerating cryomodules and one β=0.085 buncher cryomodule were installed in the FRIB tunnel and cooled down to 4 K by liquid helium. Both resonators and solenoids in the cryomodules were energized to the full accelerating fields ready for beam in a few days. To allow beam acceleration to energies well above the Coulomb barrier, the FRIB tunnel was designated as radiation restricted area with strict access control. Shielding is the primary line of defense. Radiation monitors are mounted at temporary penetrations to the FRIB tunnel to monitor safety interlocks for possible prompt radiation. A radiation survey is mandated to monitor induced radiation before planned access.

The ARR3 beam commissioning of linac segment 1 (LS1) met all goals ahead of project baseline schedule. The detailed studies of beam dynamics in the front end and the first three cryomodules of LS1 conducted during ARR1 and ARR2 were reported in reference [3]. Three one-week beam shifts were scheduled from February to April 2019 alternating with the ongoing equipment installation in the tunnel. Starting with low beam power of < 2 W, we applied a phase scan procedure to all 104 SC cavities to accelerate the $^{40}Ar^{9}$+ beam to 20.3 MeV/u. The transverse beam dynamics was verified by beam profile measurements and evaluation of the beam Courant-Snyder parameters and rms emittances. $^{20}Ne^{6}$+, $^{86}Kr^{17}$+ and $^{129}Xe^{26}$+ were also accelerated to a beam energy of 20.3 MeV/u by simply scaling all electromagnetic fields with respect to $^{40}Ar^{9}$+, tuned with appropriate charge-to-mass ratios. The beam transmission through the LS1 was 100% for all beams with measurement uncertainty < 1%. The beam-charge state distributions after the stripper were measured by using a 45 degree bending magnet and charge-state selection slits. The maximum allowable beam power is limited by the air-cooled beam dump at folding segment 1 (FS1) at 500 W. We delivered high-power equivalent beam to the beam dump in two modes: pulsed and CW. The high-power equivalent argon beam with peak intensity of 3.8 pμA and 10% duty cycle was accelerated and delivered to the beam dump. Then, the peak intensity was increased up to 14.8 pμA, which is 30% of the FRIB design value

Figure 4. FRIB cryoplant operating at both 4 K and 2 K.

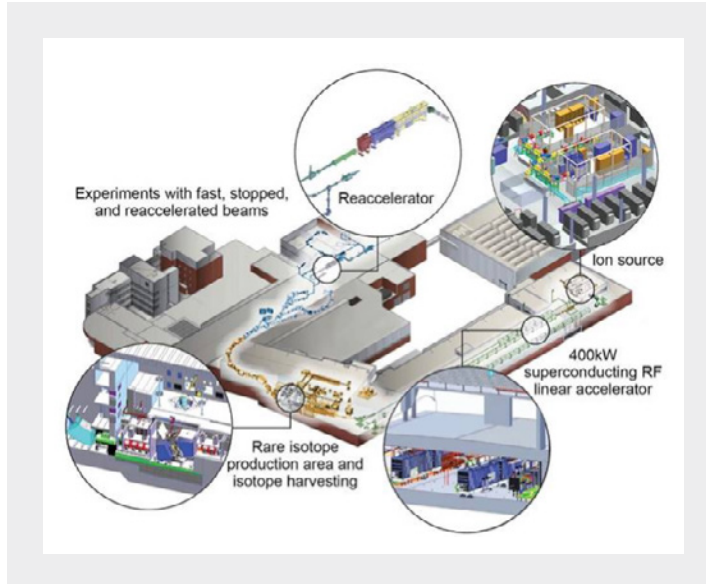

Figure 5. Schematic layout of the FRIB accelerator complex.

at 3% duty factor. 0.36 pμA argon beam was accelerated in CW mode demonstrating that FRIB linac in current configuration is the highest energy CW superconducting hadron linac in the world. A number of physics applications were successfully tested, including central trajectory correction with the "optics response matrix" (ORM) method, phase scan and field calibration, and on-line beam matching using profile monitor data. The LLRF control system compensated the beam loading while keeping the cavity voltage constant with an accuracy of < 0.1%.

The helium refrigeration system operating with the main compressors met all the design goals and has been continuously operating at 4.5 K temperature since April 2018, efficiently supporting the phased commissioning of the cryomodules. Similarly, the 2 K system was tested in December 2018 and met all the design goals for the linac operations, as shown in Fig. 4. Most of the refrigeration subsystems were designed by the FRIB cryogenic design team consisting of members from JLab and MSU, and procured from the industry as build-to-print [4]. The team is also responsible for the planning, integration, installation, controls, commissioning and operations of the entire system. The careful planning and execution prevented the need to store or "double-handle" any equipment.

Fabrication and installation of cryomodules with β=0.29 and 0.53 HWRs is proceeding in parallel [5]. Development of β=0.65 elliptical resonators is on-going, supporting the FRIB energy upgrade to 400 MeV/u, as shown in Fig. 5. ARR4, scheduled for March 2020, aims at accelerating heavy ion beams like argon to about 200 MeV/u using the 15 QWR cryomodules in LS1, and 12 β=0.29 and 12 β=0.53 HWR cryomodules in LS2. Subsequent ARRs aim at continued acceleration of the primary beam with the remaining 6 β=0.53 HWR cryomodules and transporting through the space reserved for FRIB energy upgrade in LS3 striking the production target arriving at the beam dump, production of the rare isotope secondary beam at the target and transporting through the newly constructed fragment separator and reconfigured experimental areas (Table 1).

ARR Phase	Area with beam	Energy MeV/u	Date
ARR1	Front end	0.5	2017-7
ARR2	+ β=0.041 CM	2	2018-5
ARR3	+ β=0.085 CM	20	2019-2
ARR4	+ LS2 β=0.29, 0.53 CM	200	2020-3
ARR5	+ LS3 β=0.53 CM	>200	2020-12
ARR6	+ target, beam dump	-	2021-9
Final	Integration with NSCL	-	2022-6

Table 1. Stages of accelerator readiness (ARR) for the phased beam commissioning of the FRIB accelerator.

In summary, the FRIB project is on target to achieve its design goals advancing the frontier of heavy ion beam power by more than two orders of magnitude. Nearly five years after the start of technical construction of the project, FRIB is progressing on schedule and on cost with beam commissioning proceeded through the first 15 of the total 46 superconducting cryomodules and heavy ions accelerated above 20 MeV/u. Operations for scientific users is expected to start as planned in 2022.

References

1 J. Wei, Mod. Phys. Lett. A, 31, 1630010 (2016)
2 J. Wei et al, Inter. Journal Mod. Phys. E, 28, 1930003 (2019)
3 P. Ostroumov, et al., Phys. Rev. Accel. Beams, 22, 040101 (2019)
4 V. Ganni et al, CEC-ICMC 59, 323 (2013)
5 T. Xu et al, LINAC'14, Geneva, 155 (2014)

HL-LHC Status

Lucio Rossi and Giorgio Apollinari
CERN and Fermi National Accelerator Laboratory

The LHC is a breakthrough machine. The 2012 observation of the Higgs boson, the simplest possible type of elementary particle (no spin, no charge, only mass) and yet the last predicted particle of the Standard Model to be observed, has shown once more that we do not have a clear understanding for what can explain the mass of the Higgs itself. The Higgs appears as a "lonely beast, unaccompanied by other particles" [1], which provides even more motivation to keep searching for hints of Beyond the Standard Model physics at the LHC. These searches rely on higher energy and higher luminosities.

The LHC is now operating at a center-of-mass energy of 13 TeV and is expected to reach the design energy of 14 TeV in the next few years. The LHC also achieved a record instantaneous luminosity of 2.1x10^{34} cm^{-2} s^{-1}, twice the nominal design value. In addition, in terms of integrated luminosity, LHC is doing pretty well: During Run 1 and Run 2, approximately 190 fb^{-1} were delivered to each of the two high luminosity experiments ATLAS and CMS, which is more than 20% higher than the target value of 150 fb^{-1}.

After Run 3 (Fig. 1), when both ATLAS and CMS plan to have collected at least 350 fb^{-1} of proton collisions, the LHC will face two major facts:

- The magnets providing the beam squeeze in the experiments will be heavily irradiated by particle debris escaping from collision points and enter into the regime of radiation damage, needing a replacement that would requires a long stop of the machine. It has to be noted that also the inner trackers of the experiments will be heavily damaged by radiation and will be in need of either a major refurbishment or a full replacement.

- The statistical gain in running the accelerator without a significant luminosity increase beyond its design and ultimate values will become marginal. To maintain scientific progress and to exploit its full capacity, the LHC will need to have a decisive increase in its luminosity after 2020.

All this concurs with calling for a major upgrade of the machine and of the experimental detectors in a coordinated long shutdown after Run 3, i.e., in the middle of the 2020s.

The priority to fully exploit the potential of the LHC has been confirmed as the first priority among the "high priority large-scale scientific activities" in the new European Strategy for Particle Physics—Update 2013 [2]. The importance of the LHC luminosity upgrade for the future of high energy physics was also reaffirmed

Figure 1. Timeline for the LHC and HL-LHC Plans.

in the May 2014 recommendation by the Particle Physics Project Prioritization Panel (P5) to the High Energy Physics Advisory Panel (HEPAP), which in turn advises the U.S. Department of Energy (DOE) [3]. In this context, CERN launched the High Luminosity LHC (HL-LHC) project at the end of 2010 [4]. Started as a design study, and after the approval of the CERN Council in May 2013 and the insertion of a consistent part of the HL-LHC budget in the CERN Medium Term Plan (MTP), the HL-LHC has become CERN's major construction project for the next decade. The HL-LHC Project was approved in the 181th session of the CERN Council in June 2016 [5]. It is remarkable that HL-LHC has become the first project formally approved by the CERN Council since the final approval of the LHC in 1996.

The HL-LHC Upgrade was envisioned from the beginning as an international project. Indeed, U.S. laboratories started to work on it with considerable resources well before CERN. In 2002 and 2003, a collaboration between the U.S. laboratories and CERN established a first road map for LHC upgrade [6]. The LHC Accelerator R&D Program (LARP) was then set up and approved by DOE. Two European FP7 programs (SLH-PP and EuCARD) helped to reinforce the design and R&D work for the LHC upgrade in Europe. KEK in Japan, in the framework of the permanent CERN-KEK collaboration, also engaged from 2008 in activities for the LHC upgrade. LARP remained, until 2011, the main R&D activity in the world for the LHC upgrade. Today, the HL-LHC Collaboration includes more than 20 nations and more than 45 participating institutions across the globe.

HL-LHC Goals

The main objective of the High Luminosity LHC design study was to determine a set of beam parameters and the hardware configuration that will enable the LHC to reach the following targets:

- A peak luminosity of 5 × 1034 $m^{-2}s^{-1}$ with levelling, allowing the next target.
- An integrated luminosity of 250 fb^{-1} per year with the goal of 3000 fb^{-1} in about a dozen years after the upgrade. This integrated luminosity is about 10 times the expected luminosity reach of the first 12 years of the LHC's lifetime.

The overarching goals are the installation of the main hardware for the HL-LHC during LS3 (scheduled 2024–2026) and finishing the hardware commissioning at machine re-start in 2026, while taking all actions to assure a high efficiency in operation until 2035–2040.

All of the hadron colliders in the world before the LHC have produced a combined total integrated luminosity of approximately 10 fb^{-1}. The LHC delivered approximately 190 fb^{-1} to each high-luminosity experiment by the end of 2018 and will reach approximately 350 fb^{-1} in its first 13–15 years of operation. The HL-LHC is a major, extremely challenging, upgrade. For its successful realization, a number of key novel technologies have been developed and are being validated, and will be integrated in the main LHC machine.

The HL-LHC parameters following the design study are summarized in Table 1.

Parameter	Nominal LHC (design report)	HL-LHC 25 ns (standard)	HL-LHC 25 ns (BCMS)[3]	HL-LHC 8b+4e[4]
Beam energy in collision [TeV]	7	7	7	7
N_b [1011]	1.15	2.2	2.2	2.3
n_b	2808	2748	2604	1968
Beam current [A]	0.58	1.09	1.03	0.82
Minimum β* [m]	0.55	0.2	0.2	0.2
εn [μm]	3.75	2.50	2.50	2.20
εL [eVs]	2.50	2.50	2.50	2.50
Peak luminosity with crab cavities [10^{34} $cm^{-2}s^{-1}$][3]	(1.18)	12.6	11.9	11.6
Levelled luminosity for μ =140 [10^{34} $cm^{-2}s^{-1}$]	-	5.321	5.02	5.03
Events/crossing μ (with levelling and crab cavities)[2]	27	140	140	140
Maximum line density of pile-up events during fill [ev/mm][5]	0.21	1.3	1.3	1.3

Table 1. Main Parameters of HL-LHC.

1 For the design of the HL-LHC systems (collimators, triplet magnets, etc.), a design margin of 50% on the stated peak luminosity was agreed upon.
2 The total number of events/crossing is calculated with an inelastic cross-section of 85 mb (also for nominal), while 111 mb is still assumed for calculating the proton burn off and the resulting levelling time.
3 The current baseline foresees installation of 1⁄2 crab-cavity modules in LS3 and an option for 1⁄2 in LS4, having an initial impact on parameters like β*, crossing angle, virtual luminosity reach and levelling time. The current HL-LHC baseline foresees the installation of 16 cavities of maximum voltage of 3.4 MV. Space will be reserved to optionally install the second half at a later stage after LS3.

HL-LHC: Technical Description

The high luminosity configuration requires upgrades of numerous existing systems. The most striking example is the replacement of the inner triplet magnets with new magnets of different technology based on the Nb_3Sn superconductor. This will constitute the backbone of the upgrade. Another case is the replacement of a good part of the present collimation system with an improved design with lower impedance jaws.

In other cases, new equipment not included in the present LHC layout will be installed in order to increase performance, in terms of either peak luminosity or availability. The most important example is the superconducting RF crab cavities, which are of a compact design as required for the HL-LHC, comprising a completely new development installed for the first time on a proton collider.

The major systems requiring an upgrade are insertion region (IR) magnets, crab cavities and the collimation system. In addition to these systems, upgrades will be introduced also for collision debris absorbers; cold powering; machine protection and remote handling; new cryostat plants and distribution to disentangle cooling of the inner-triplets regions and the main arcs; enhanced beam instrumentation and new beam transfers elements (absorbers and kickers).

HL-LHC: Status of Activities

In 2019, the HL-LHC project transitioned from design and R&D to industrialization and construction, experiencing a mix of successes and difficulties.

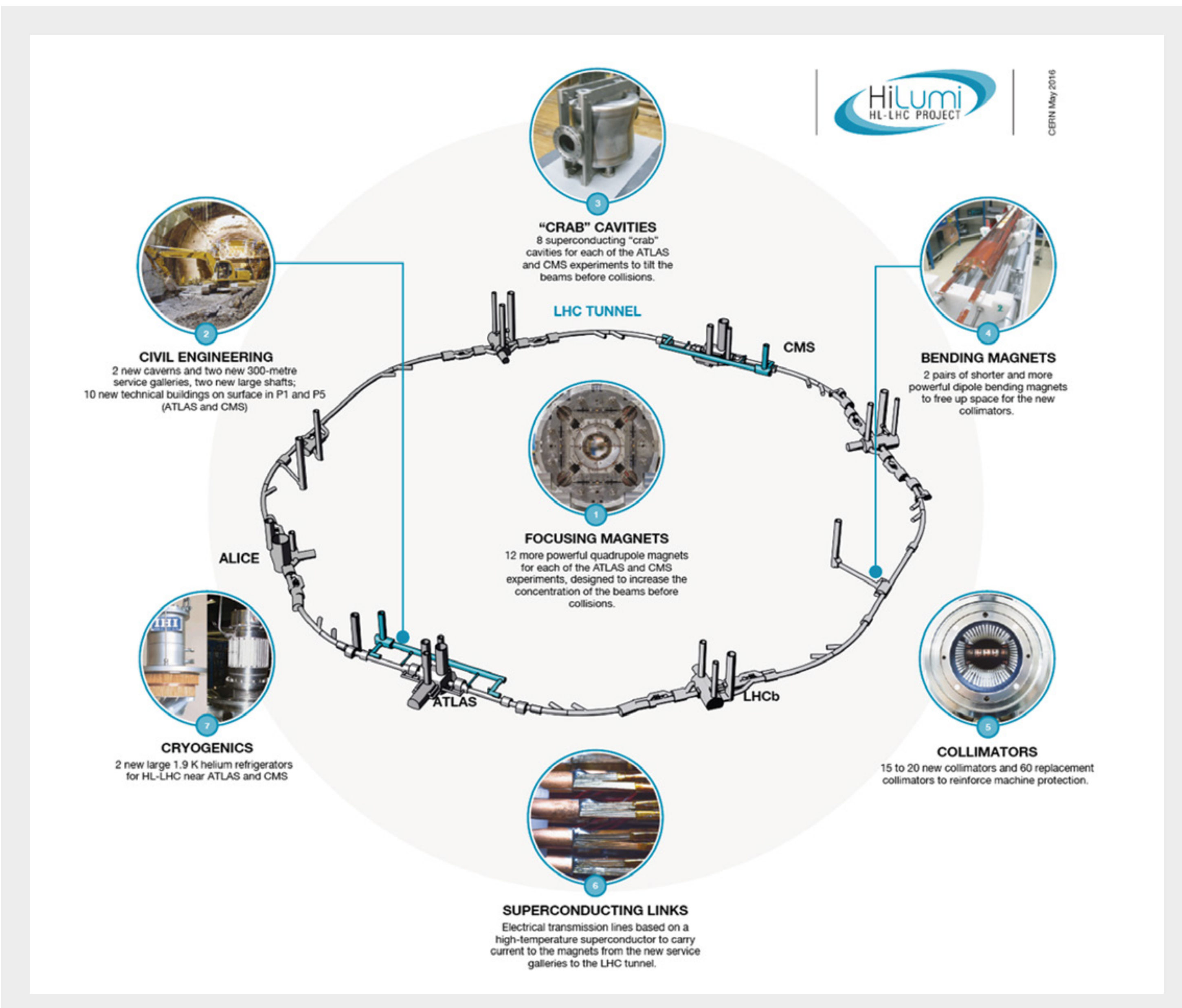

Figure 2. Pictorial representation of the major system upgrades for HL-LHC.

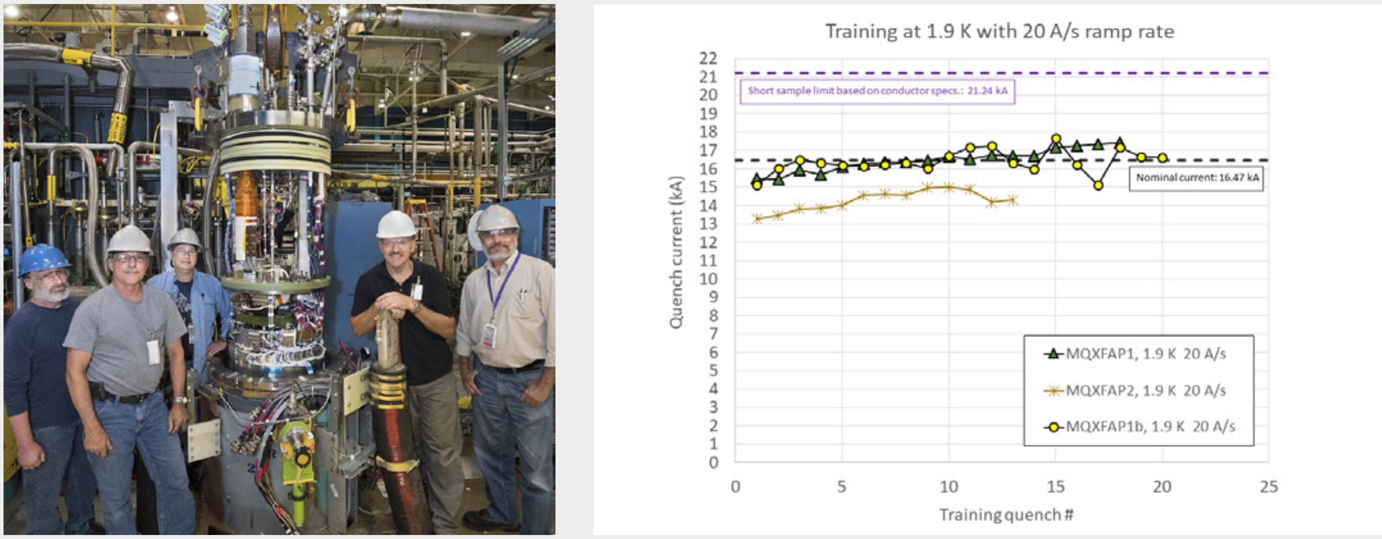

Figure 3. Test of the last LARP prototype MQXFAP1b ready for test at BNL (left) and quench behavior of the long quadrupole prototype tested so far. MQXFAP2 was limited by a mechanical structure failure.

The most delicate point is certainly the unexpected marginal behaviors of some prototypes and model magnets. The HL-LHC magnets are all state-of-the art. The new, critical Nb_3Sn technology, deployed for the IT quadrupoles and for the 11 T dipoles, is particularly challenging. In particular, Nb_3Sn prototypes for Q1/Q3 inherited from the LARP programs have performed well up to nominal current (Fig. 3), but failed to reach ultimate current. In one case (MQXFAP2 in Fig. 3), an understood mechanical issue caused the fracture of the magnetic structure, preventing a full test of the magnet.

The first Q1/Q3 pre-production HL-LHC quadrupole (MQXFA03) is under construction in the U.S. and will be tested in fall 2019, benefiting from all lessons learned from the LARP prototypes. The first long Q2 prototype is under construction at CERN, to be tested in spring 2020.

The first 11 T, 5.5 m long dipole in Nb_3Sn has been recently tested and qualified for installation in the tunnel at CERN. All other new NbTi magnets are, either for size or energy or for technology reasons, a step beyond the LHC ones. Some issues related to premature quenches or electrical faults have been already solved.

A very successful test was carried out on the first demonstrator of the cold powering: For the first time, a 60 m long superconducting line with MgB_2 carrying 20 kA (Fig. 4) was powered at the temperature slightly beyond 20 K. The system showed a high reliability, cryogenic consumption in line with the design and exceptional stability. Meanwhile, the first piece of HL-LHC equipment was installed in the LHC during LS2: the TANB, a small absorber that protects the superconducting magnets in the region IR8 around the experiment LHCb, which will increase its luminosity by a factor of 5 despite remaining still well below the ones of ATLAS and CMS. More equipment that will be installed soon, the shielding for the interface of the collider with the ATLAS and CMS experiments, has been completed at PAEC in Pakistan and is almost ready for installation in November 2019.

Another successful test was performed on the crab cavities system by installing and testing a fully integrated cryomodule in the SPS (Fig. 5). The two first crab cavity prototypes were manufactured at CERN in 2017 in collaboration with Lancaster University and the Science and Technology Facilities Council (STFC) in the United Kingdom, as well as the U.S. LARP Program. The cavities were assembled in a cryostat and tested at CERN. The cavities were installed in the SPS accelerator during the 2017–2018 winter

Figure 4. MgB2 60-meter-long superconducting line with team members at CERN.

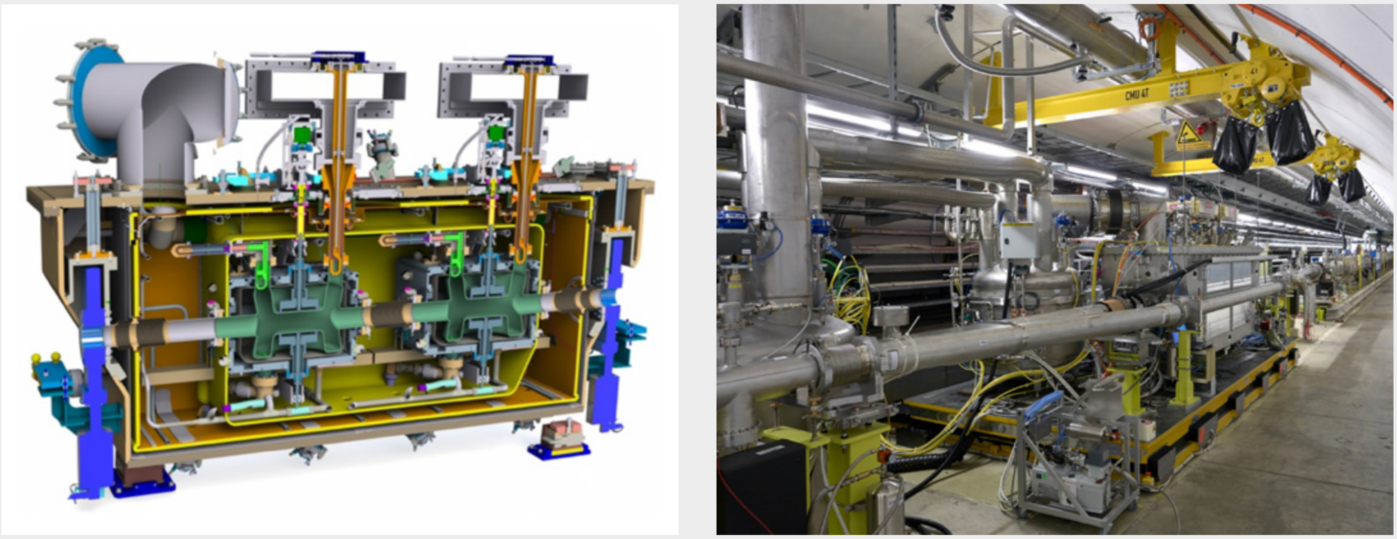

Figure 5. Cross-sectional view of the SPS crab cavities cryomodule (left) and SPS installation of the same.

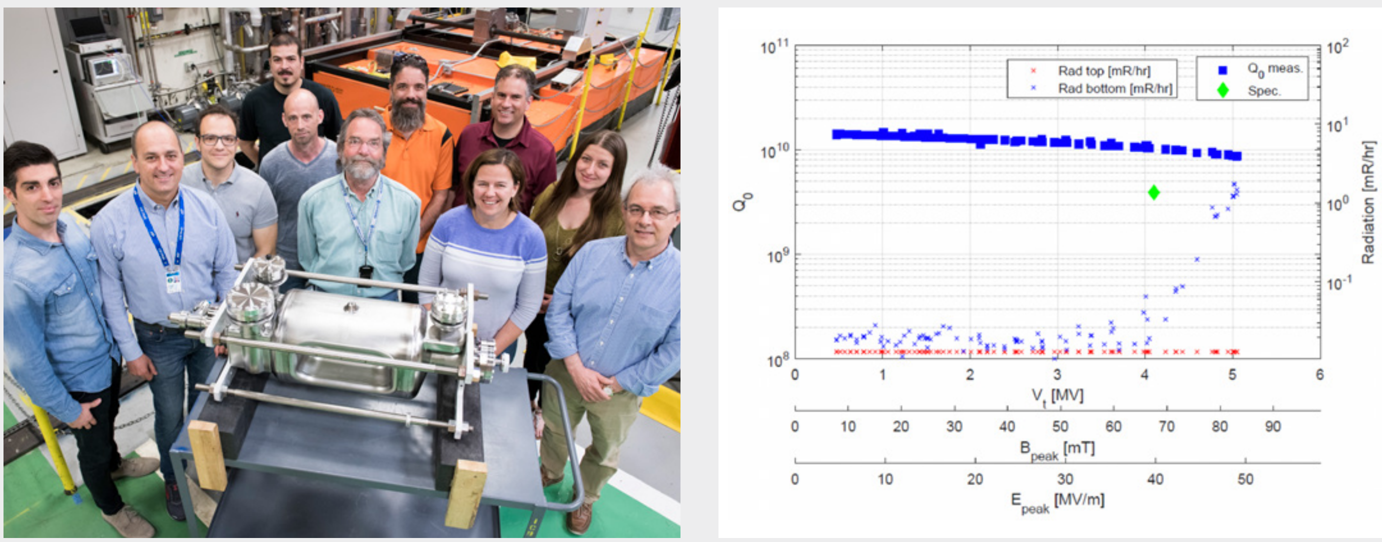

Figure 6. RFD crab cavity team (left) and quench performance of the RFD cavity. The green star indicated the HL-LHC specified operating point.

technical stop to undergo validation tests with proton beams. The first beam tests on May 2018 lasted for more than 5 hours at a temperature of 4.2 K with a single proton bunch accelerated to 26 GeV and containing between 20 and 80 billion protons, almost the intensity of the LHC bunches. The crab cavities were powered to about 10% of their nominal voltage. The crabbing was observed using a special monitor to observe the tilt along the length of the bunch. In the coming months, the cavities will be commissioned to their nominal voltage of 3.4 MeV and will undergo a series of tests to fully validate their operation for the HL-LHC era.

In the U.S., one RFD prototype from LARP was chemically processed at ANL and tested at Fermilab (Fig. 6), exceeding the

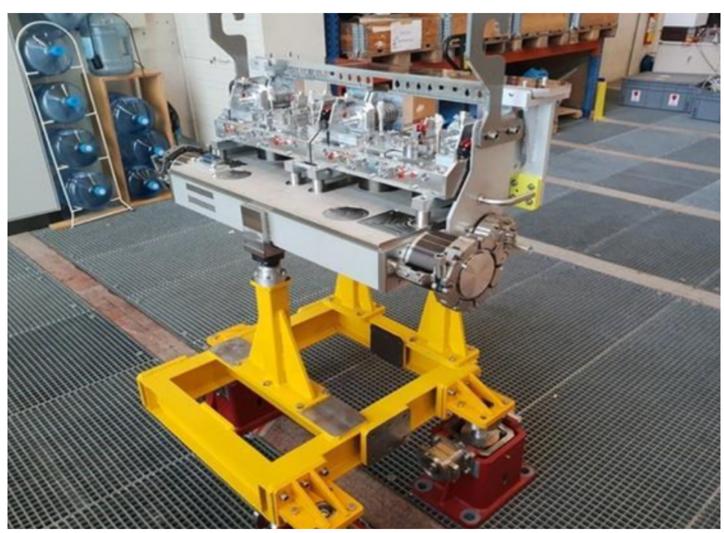

Figure 7. First TCLD collimator at CERN.

Figure 8. Base of the access shaft in Point 1 and start of the cavern excavation.

HL-LHC field and Q0 specifications and validating facilities, procedures and tooling specific for crab cavities. The bulk chemical processing was performed with a BCP rotating system developed specifically for the Accelerator Upgrade Project. Procurement of AUP prototype RFD cavities is now in process, and the pre-series cavities are expected toward the end of 2020.

The first industrially built target collimator long dispersion suppressors arrived at CERN in early 2019 (Fig. 7). The TCLD consists of two high-precision, movable tungsten jaws that embed precise beam-position monitors. A first prototype has been successfully completed in-house at CERN. The main production has been outsourced to industry, where four operational units and one spare are being built. The TCLD collimators will be some of the first HL-LHC devices to be used with beam in the LHC at the startup after LS2.

The civil engineering work is proceeding very well with minor delays or issues. Not only are the two large pits finished, but the main caverns that will host the new large cryoplants and other technical services are almost all excavated (Fig. 8). Now, the contractors are tackling the long underground galleries that will host the power supplies of the new HL-LHC magnets. Civil-engineering works, including surface buildings, will be completed by the autumn of 2022, about one year before the long shutdown LS3 starts.

References

1 N. Arkani-Hamed, "In it for the long haul", Opinion interview in CERN Courier, Mar./Apr. 2019

2 The European Strategy for Particle Physics Update 2013, CERN-Council-S/106, adopted at a special session in Brussels on 30 May 2013, CERN (2013). http://cern.ch/council/en/EuropeanStrategy/ESParticlePhysics.html

3 Building for Discovery: Strategic Plan for U.S. Particle Physics in the Global Context, US DOE (2014). http://science.energy.gov/hep/hepap/reports/

4 L. Rossi, LHC Upgrade Plans: Options and Strategy, 2nd International Particle Accelerator Conference, San Sebastian, Spain, 4 - 9 Sep 2011, pp.TUYA02, p. 908. CERN-ATS-2011-257

5 The High-Luminosity LHC Project (Director-General) 298th Meeting of Scientific Policy Committee; CERN/SPC/1068 ; CERN/FC/6014 ; CERN/3255, CERN (2016)

6 J. Strait et al. "Towards a New LHC Interaction Region Design for a Luminosity Upgrade", 20th IEEE Particle Accelerator Conference, Portland, OR, USA, 12 - 16 May 2003, pp.42-4, CERN-LHC- Project-Report-643 (2003).

Further Reading

7 E. Todesco et al., "Design studies for the low-β quadrupoles for the LHC luminosity upgrade," IEEE Trans. Appl. Supercond., vol. 23 no. 3, pp. 4002405, Jun. 2013, doi:10.1109/TASC.2013.2248314

8 E. Todesco, et al., "A first baseline for the magnets in the high luminosity LHC insertion regions," IEEE Trans. Appl. Supercond., vol. 24 no. 3, pp. 4003305, Jun 2014, doi:10.1109/TASC.2013.2288603

9 P. Ferracin et al., "Magnet design of the 150 mm aperture low-β quadrupoles for the High Luminosity LHC," IEEE Trans. Appl. Supercond., vol. 24 no. 3, pp. 4002306, Jun. 2014, doi:10.1109/TASC.2013.2284970

10 E. Todesco et al., "Progress on HL-LHC Nb_3Sn Magnets", IEEE Trans. Appl. Supercond., vol. 28 no. 4, pp. 4008809, Jun. 2018, doi:10.1109/TASC.2018.2830703

11 R. Bruce, A. Marsili and S. Redaelli, Cleaning performance with 11 T dipoles and local dispersion suppressor collimation at the LHC, Proc. 5th International Particle Accelerator Conference, Dresden, Germany, 15 - 20 June 2014, Eds. C. Petit-Jean-Genaz, pp.MOPRO042.

12 A. Piwinski, Nucl. Inst. Meth. 81, 199 (1970)

13 R. Calaga "Crab cavities for the High-Luminosity LHC", in Proc. of the 18th International Conference on RF Superconductivity (SRF2017), Lanzhou, China, Jul. 2017, doi:10.18429/JACoW-SRF2017-THXA03.

14 R. Calaga et al., "First machine development results with HL-LHC Crab Cavities inside the SPS", presented at the 10th Int. Particle Accelerator Conference (IPAC19), Melbourne, Australia, May 2019, this conference.

15 R. Calaga "First Crabbing of Proton Beam", presented at the TESLA Technology Collaboration Meeting (TTC 2019), Vancouver, CA, Feb. 2019

16 S. De Silva et al., "Design and Prototyping of a 400 MHz RF-dipole Crabbing Cavity for the LHC High-Luminosity Upgrade", in Proc. IPAC'15, Richmond, VA, USA, May 2015, doi:10.18429/JACoW-IPAC2015-WEPWI036.

17 S. De Silva et al., "RF Test of RF-Dipole Prototype Crabbing Cavity for LHC High Luminosity Upgrade", in Proc. of the 18th International Conference on RF Superconductivity (SRF2017), Lanzhou, China, Jul. 2017, doi:10.18429/JACoW-SRF2017-TUPB054.

Plans Advance for the Next Big Collider at CERN

Panagiotis Charitos and Rickard Ström *CERN*

The Update of the European Strategy for Particle Physics (ESPP) is a major exercise designed to guide the research and priorities of the European particle physics community. The current update was initiated by the CERN Council in 2016 and is due to be finalized by May 2020. The Open Symposium held in Granada, Spain, May 13–16, 2019, was an important milestone during which the community was invited to debate the scientific inputs provided by different projects, countries and community members. The aim of the updated strategy is to reflect upon the worldwide status and developments in high-energy particle physics, articulate the priorities and, ultimately, identify the projects that should be pursued. Both the Future Circular Collider (FCC) and Compact Linear Collider (CLIC) projects have submitted extensive documentation as input, each describing their physics case and project implementation plan. Following the four-day symposium in Granada, the physics preparatory group prepared a "briefing book" summarizing the scientific contributions to the European Strategy Group. The latter is the main body responsible for establishing a set of recommendations to be presented to the CERN Council for approval in mid-2020. It should be noted that the strategy also covers other topics, for example neutrino physics and "physics beyond colliders" as well as detector instrumentation and computing.

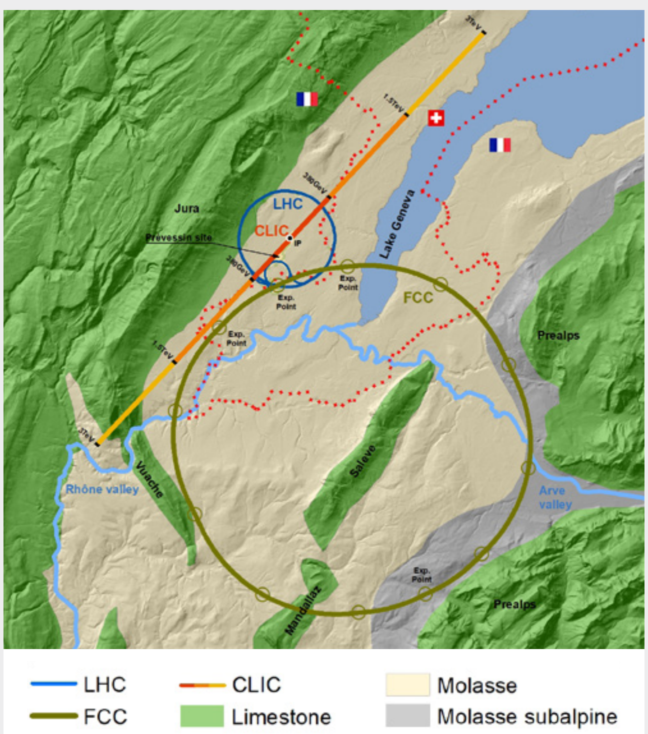

Figure 1. Footprint of CLIC and FCC: Footprint of the proposed CLIC (orange lines) and FCC (green circle) projects for a possible implementation at the research centre CERN in Geneva, Switzerland. The current collider infrastructure, including the Large Hadron Collider (LHC), is shown in blue. **Credit:** CERN (https://cds.cern.ch/record/2689893 , CC-BY-4.0)

Proposals for the Next Machine at CERN

FCC-ee

The FCC-ee is the first stage of an integrated research program based on a new research infrastructure hosted in a 100 km tunnel at CERN: the Future Circular Collider. It will be implemented in stages as an electroweak, flavour and Higgs factory, spanning the energy range from the Z pole (90 GeV) to the top pair production threshold (up to about 380 GeV). The FCC-ee is optimized to study the Z, W, Higgs and the top quark with high precision, acquired in the clean lepton collision environment.

The FCC design is based on the experience of the Large Electron-Positron Collider (LEP) and inspired by the progress made for modern storage-ring light sources and colliders including the Double Annular Φ Factory for Nice Experiments at the INFN Frascati National Laboratory, B-factories with elements such as top-up injection, strong focusing, and crab-waist optics, offering

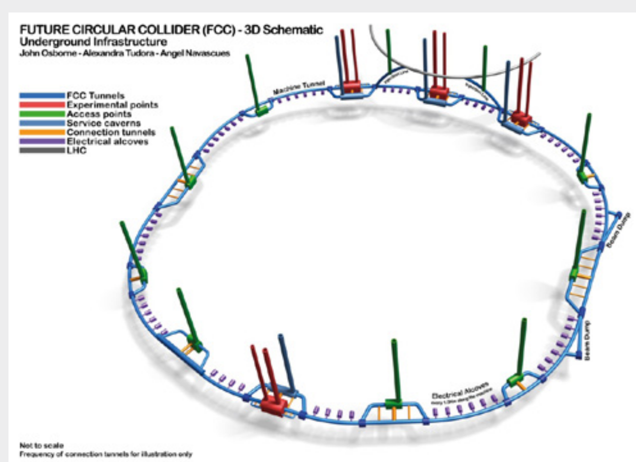

Figure 2. FCC tunnel layout: Schematic of the 100 km long FCC tunnel showing the baseline layout including four large caverns (red) that could host future experiments. **Credit:** CERN (https://cds.cern.ch/record/2653532/)

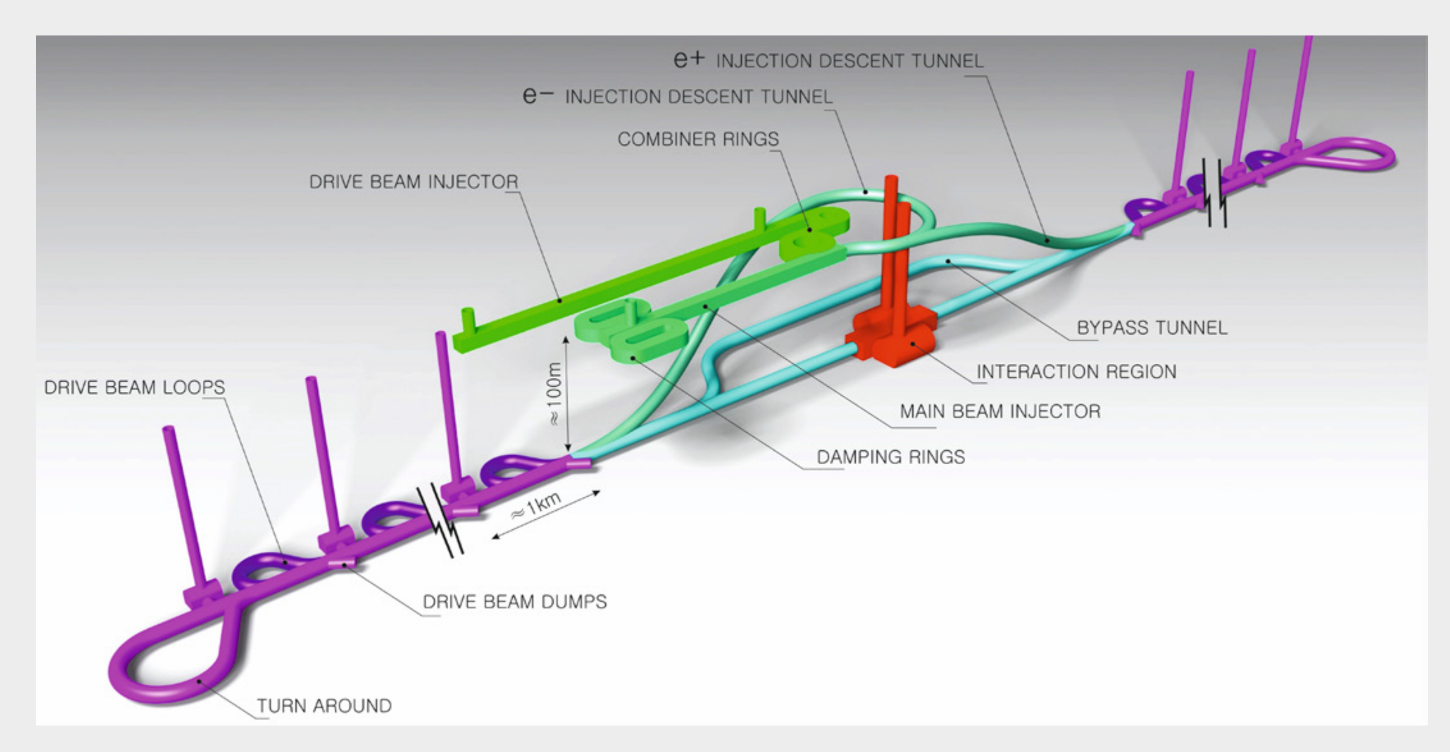

Figure 3. CLIC tunnel layout: Schematic of the, up to 50 km long, laser-straight CLIC accelerator complex including drive- and main beam tunnels. **Credit:** CLIC

luminosities up to 10^5 times larger than achieved at LEP. The FCC-ee would feature two or four interaction points. The main technological components of the collider are its superconducting RF (SRF) system based on thin-film niobium-on-copper technology, with an operating field about three times higher than at LEP, and low-power low-field twin-aperture arc magnets plus the arc vacuum system with integrated photon stops and novel, ultra-thin non-evaporable getter coating. The design foresees, for the highest energy to reach the top threshold with moderate beam current, the addition of 5-cell bulk niobium cavities. Ongoing R&D on more advanced technologies, high-efficiency klystrons or solid-state amplifiers, could further boost the performance and energy-efficiency of this machine. The lower synchrotron radiation loss compared to LEP in the 100 km ring coupled with the compensation provided by the RF cavities and novel technological solutions, including a top-up injection scheme and the innovative optics design with asymmetric final-focus layout and "virtual" crab waist, would enable FCC-ee to attain even higher luminosity.

Realization of the FCC-ee is based on a preparatory phase followed by a 10-year construction phase starting around 2028. This will include all civil and technical infrastructure as well as machine and detector commissioning. A duration of 15 years is projected for the operation of the FCC-ee facility, to complete the currently envisaged physics program.

CLIC380

The Compact Linear Collider is a proposed future linear electron–positron collider that would be implemented in three stages, providing high-luminosity collisions at centre-of-mass energies of 380 GeV, 1.5 TeV, and 3 TeV, with a main linac tunnel length ranging between 11 km and 50 km. Detailed studies on Higgs and top-quark physics concluded that the optimal center-of-mass energy for the first stage of CLIC is 380 GeV. This allows very precise studies of the Higgs boson, the top quark, and other standard model (SM) particles and processes, and for direct searches for new particles, exotic Higgs decays, and other beyond standard model (BSM) physics. The physics potential of a linear collider is enhanced by the option to use polarized beams, a tool that offers unique access to the chirality of couplings and the structure of interactions, as well as a handle to deal with some of the most challenging background processes. Longitudinal electron polarization is foreseen at all three stages.

CLIC is powered by an innovative two-beam accelerating scheme, in which a low-energy, high-current drive beam is used to generate short, high-peak radiofrequency pulses for efficient acceleration of the two main beams of electrons and positrons. With this technology, the normal conducting accelerating structures of the main linac achieve a high accelerating gradient of 72 MV/m and thus allow for the construction of a compact accelerating complex. The drive beam is generated using conventional low-frequency klystrons that efficiently produce long RF-pulses. These are compressed into several short, high-power beam pulses in a series of combiner rings and subsequently transported alongside the main linac, where the stored energy is extracted and transferred via waveguides into the accelerating structures. The two-beam acceleration scheme allows for a compact and cost-effective accelerator with an upgrade path. Beyond increasing the linac lengths, R&D is ongoing for higher gradients, for example by improving the X-band accelerating structures. The CLIC project features an advanced detector concept that matches the physics performance requirements.

The CLIC project can move forward quickly towards implementation, and be ready for expanding and deepening Higgs studies and Standard Model precision measurements within about 15 years, possibly overlapping with the High-Luminosity Large Hadron Collider (HL-LHC) program. The construction of the first energy stage could start by 2026, after a 7-year preparation phase focusing on technical, industrial and site readiness.

Upgrade Options

CLIC1500/3000

A clear advantage of any linear machine is that it can be upgraded in a straightforward way to reach higher energy and is therefore also flexible in the choice of design collision energy. Guided by the results from possible new discoveries at the HL-LHC or previous operation of CLIC, the collider could be upgraded to reach energies up to 3 TeV at an accelerating gradient of 100 MV/m. For CLIC in particular this can be done in a cost- and power-effective way by lengthening the main linac tunnel and reinforcing the drive-beam production, for example by adding additional drive-beam pulses. Upgrading to 1.5 TeV and 3 TeV involves extending the main linac tunnel to 29 km and 50 km, respectively. In addition, above 1.5 TeV a second drive-beam complex is needed. The construction of the higher energy stages can, to a large extent, take place in parallel with taking data.

Studying lepton collisions at higher energies would significantly improve the precision tests of the SM parameters and the sensitivity to BSM physics by opening new production channels and testing energy dependencies. The higher collision energies allow the measurement of the Higgs self-coupling, a critical fundamental property of the Higgs field, giving unique sensitivity to its SM or non-SM nature. In addition, the reach of direct searches for BSM physics increases dramatically. Each of the three energy stages are cornerstones of the CLIC physics program; for example, the Higgsstrahlung process gives access to the Higgs width at the initial energy stage of CLIC, while the impact of different BSM effects can be disentangled effectively using measurement at several energy stages.

The CLIC infrastructure is also of interest for studies of linear lepton and photon colliders in the far future, including future colliders that make use of new accelerator technologies, such as plasma wakefield-based or dielectric-based acceleration. Although these technologies are not yet mature and need more studies to reach the desired beam quality and power efficiency, they hint towards the realization of much more compact particle accelerators and thus interesting upgrade paths for a linear collider in the future.

FCC-hh/eh

The hadron collider envisioned by FCC-hh installed in the 100 km tunnel previously used for the FCC-ee could reach collision energies of 100 TeV, approximately seven times higher than the LHC and luminosities 50 times higher than the LHC, using new high-field superconducting magnet technology. This energy-frontier machine could produce particles with much higher masses (up to 20-30 TeV), well beyond the energy reach of the LHC. However, substantial technological developments are needed to realize such a machine as we will discuss below.

FCC-hh can precisely measure the Higgs self-coupling and thoroughly explore the dynamics of electroweak symmetry breaking at the TeV scale to elucidate the nature of the electroweak phase transition in the early universe. The FCC-hh could also give access to dark matter candidate particles with mass below 60 GeV, conclusively detecting or excluding thermal WIMPs – an important class of DM candidates. FCC-hh offers the potential for direct searches of new heavier particles and to measure Higgs couplings at sub(percent)-level precision. Moreover, the trillions of produced quarks (10^{12}) will allow the study of any flavour-changing neutral couplings of the Higgs boson that can be strongly suppressed in the SM. A duration of 25 years is projected for the subsequent operation of the FCC-hh to reach its ambitious physics goals. The integrated FCC program, combining FCC-ee and FCC-hh, enables a thorough examination of the Higgs boson and the electroweak sector.

FCC-hh can be extended to an electron-hadron collider with a center-of-mass energy of 3.5 TeV. Deep inelastic scattering is the cleanest probe to resolve the substructure and dynamics of hadronic matter. Finally, a future circular hadron collider could also operate with heavy-ion beams like presently the LHC. FCC-hh can reach energies of 39 TeV for PbPb collisions and 63 TeV for pPb asymmetric collisions with luminosities 10-30 times higher compared to LHC, opening new ways for addressing the fundamental questions about the nature of quantum chromodynamics and the strong interaction.

Technologies

Magnets – material/superconductivity

FCC-hh requires high-quality accelerator dipole magnets with a 16 T field. Although Nb_3Sn magnets reaching 11 T will be used in the HL-LHC, further advancements are needed to reach the required field for FCC. Notably, a focused R&D program to bring the

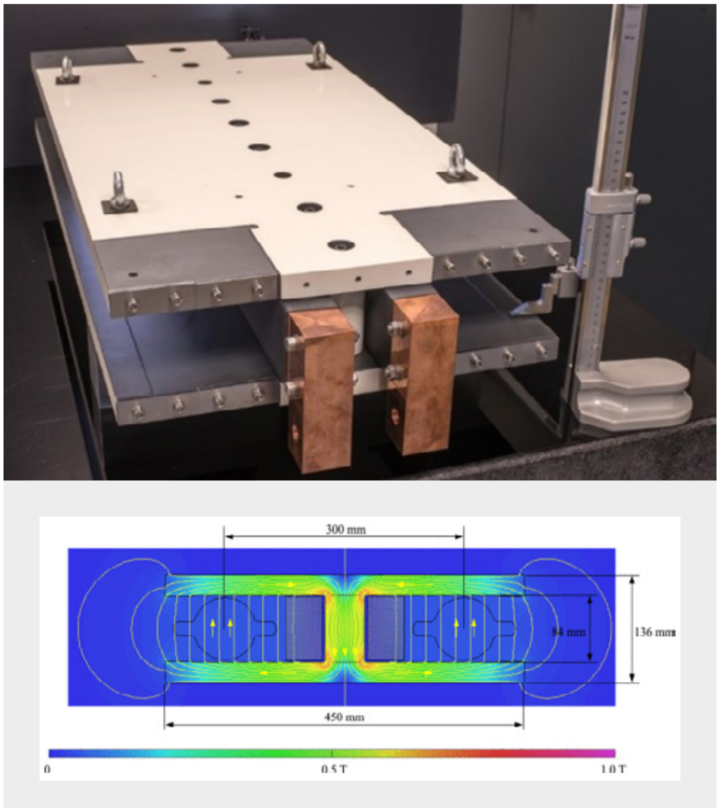

Figure 4. FCC-ee dipole: A 1 m-long prototype of the FCC-ee dipole magnet. The proposed design considerably reduces the power consumption and the total amount of material required: an energy saving of 20-30% is possible compared to the magnets previously used at the Large Electron-Positron Collider (LEP) at CERN. Last summer the first FCC-ee quadrupole magnets based on a similar design principle was also tested at CERN. **Credit:** CERN (image: https://cds.cern.ch/record/2653532)

Nb_3Sn conductor, the workforce of the FCC magnet development program, to the required 1600 A/mm^2 current density at 4.2 K temperature, has been running since 2014. Impressive results have been presented by the FCC collaborators. Unit lengths of Nb_3Sn wires with performance at least comparable to that of the HL-LHC conductor have been produced. US teams presented very promising achievements with the production of R&D Nb_3Sn wire via new technologies reaching or even exceeding the FCC target parameters. Finally, a field of 14.2 T in an advanced accelerator dipole magnet has been achieved this year in the US. An important step towards the FCC 16 T magnets.

In addition, if the FCC-hh is implemented as a second step after FCC-ee, there will be an additional window of 15 years for developing a variety of other materials, exploring the possibility of using high-temperature superconductors that could result in more powerful magnets (20-25 T) and eventually higher energy reach while reducing the operation requirements.

The cryogenic beam vacuum system is another key technology for FCC-hh. This system protects the magnets from the synchrotron radiation of the more energetic beams (50 TeV) and efficiently remove the heat produced. It features an ante-chamber and is

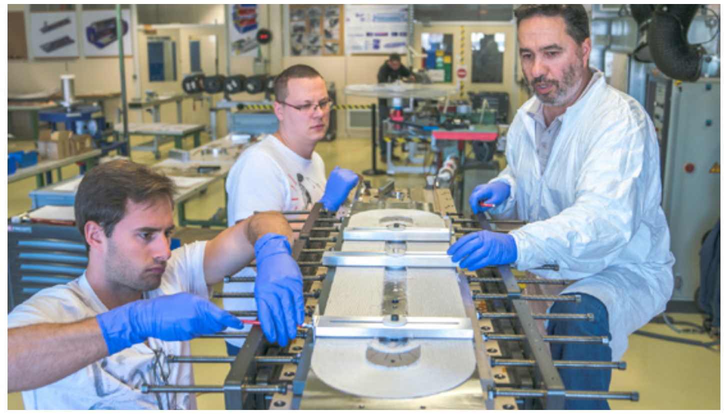

Figure 5. Winding of Nb_3Sn cable: One of the key challenges for an energy-frontier 100 TeV collider such as FCC-hh is the Nb_3Sn superconducting-magnet technology and high-field magnet development. This photo shows the winding of the enhanced racetrack model coil (eRMC) at CERN; a step towards FCC-hh 16 T magnets. **Credit:** FCC Collaboration (https://cds.cern.ch/record/2653532/)

copper-coated to limit the parasitic interaction with the beam while additional carbon coating or laser treatment can prevent electron-cloud effects.

Finally, for a future lepton collider (e.g., FCC-ee) a key element is the development of more efficient RF superconducting technologies. Recent results show that niobium-copper technology can offer high performances similar to, if not higher than, their bulk niobium counterparts. Applying novel superconducting thin-film coating technology will allow RF cavities to be operated at higher temperatures, thereby lowering the electrical requirement for cryogenics, and reducing the required number of cavities thanks to an increase in the accelerating gradient. Finally, ongoing R&D activity, carried out in close cooperation with the linear collider community, aims at raising the peak efficiency of klystrons.

High-gradient X-band technology

One of the driving design considerations for the CLIC project is compactness. For this reason, the CLIC project has made a major investment in the development of high-gradient X-band linac technology capable of gradients in excess of 100 MV/m. This results in a compact and cost-effective initial energy stage extendible to a 3 TeV collider with a length of approximately 50 km.

Accomplishing a technically challenging project such as CLIC relies on innovative design followed by prototyping and tests in a realistic environment. Numerous beam experiments and hardware tests have demonstrated that the CLIC performance goals can be met. For instance, accelerating gradients above 100 MV/m are routinely demonstrated in long-term operation in dedicated test stands at CERN and elsewhere, including KEK and SLAC.

CLIC has contributed to, and benefits from, the adoption of X-band technology at room temperature in a wide range of linac applications worldwide. High-power X-band systems are integral parts of many operating XFELs and the bases for high-gradient linacs in designs

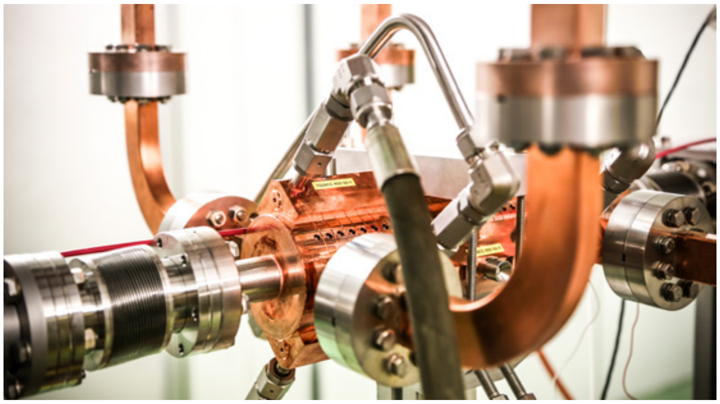

Figure 6. CLIC X-band cavity: The CLIC accelerating structures are capable of accelerating the main beams of electrons and positrons with a gradient as high as 100 million volts per metre. In order to reach such high gradients each structure needs to be carefully tested and conditioned. This photo shows a prototype of an accelerating structure for CLIC under test at the XBOX3 facility at CERN. **Credit:** CLIC/Matteo Volpi

of compact XFELs, Compton Scattering sources and medical applications. The X-band systems in these applications combined with high-power test stands at various laboratories around the world demonstrate the maturity of the technology.

Substantial progress has been made towards realizing the nanometer-sized beams required at CLIC to reach the ambitious luminosity goals. The low vertical emittances needed for the damping rings are achieved at modern synchrotron light sources such as the Swiss Light Source and the Australian Light Source. The advanced beam-based alignment of the CLIC main linac has successfully been tested at the Facility for Advanced Accelerator Experimental Tests at SLAC and the Free Electron Laser Radiation for Multidisciplinary Investigations in Trieste. The sub-nanometer stabilization of the final focus quadrupoles has been demonstrated. The significant advances achieved in these areas towards reducing the costs, improving efficiency and dealing with small and precise high-quality beams have a substantial overlap with the CLIC requirements.

Societal benefit

The technologically challenging and creative environment of fundamental science has often paved the way for unexpected discoveries with great societal benefits, such as advances in medical applications and the creation of the World Wide Web.

Large-scale research infrastructures prove to be international hubs of excellence and innovation. The long-term research programs attract industrial partners for joint development of the required technologies and provide training to numerous young researchers from all over the world. Setting up an accelerator complex like those envisioned by CLIC and FCC—from preliminary concept and design to operation—requires major involvement of industrial partners from various domains.

CERN's vibrant and stimulating environment provides not only technical experience but also opportunities to work with people

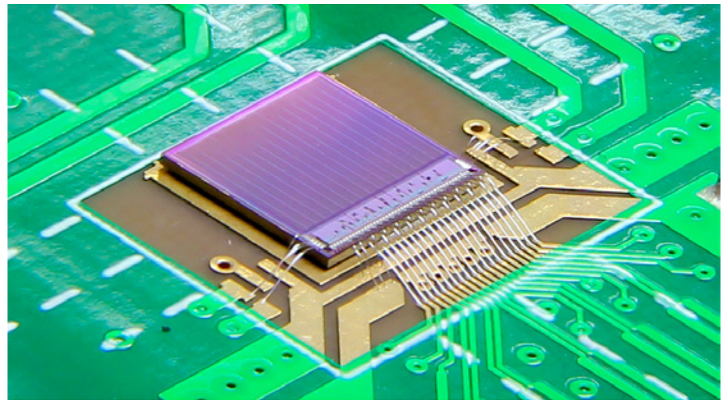

Figure 7. CLIC detector technology: A photo of a silicon-pixel detector test chip (CLICTD) designed for the requirements of the CLIC tracking detector. The chip has a footprint of 5x5 mm^2 and is produced as a monolithic CMOS detector, comprising both the sensor and the readout electronics. It contains a sensitive area segmented in 2048 readout channels, with sub-pixels of 37.5 x 30 μm^2. For testing, the prototype is connected to a printed circuit board using small aluminium wire-bonds. The CLIC tracking detector will contain roughly 140 m^2 of silicon pixel detectors. **Credit:** CERN/Mateus Vicente Barreto Pinto (https://cds.cern.ch/record/2687667)

from different cultures and knowledge domains on a very large common project. This is perhaps one of the biggest returns to society from investments in such large-scale projects.

Conclusions

While the energy scale of the potential new physics remains unknown, there is no lack of ideas on how it could manifest itself and how to best search for it. The HL-LHC program will increase the potential for new discoveries and operate into the mid-2030s, but already now discussions are intensifying on what could be the next big collider project. In this article we discussed two major options for the era beyond HL-LHC: FCC and CLIC. Both of these projects have published detailed design reports as input to the ongoing Update of the European Strategy for Particle Physics.

Significant interest has been directed towards electron–positron colliders, exploring the electroweak sector with high precision and presenting ample opportunities for the direct detection of potential new particles. On a longer timescale, these measurements combined with an ambitious R&D program could pave the way for colliders operating at much higher energies.

The recommendation of the European Strategy Group will draft its recommendations in January 2020. These discussions will shape the field for many years to come.

Further Reading

The Compact Linear Collider (CLIC) study is an international project hosted by CERN and consists of approximately 75 institutes in more than 30 countries: https://clic.cern

The Future Circular Collider (FCC) study is an international project hosted by CERN and consists of more than 140 institutes in 34 countries: http://fcc.web.cern.ch


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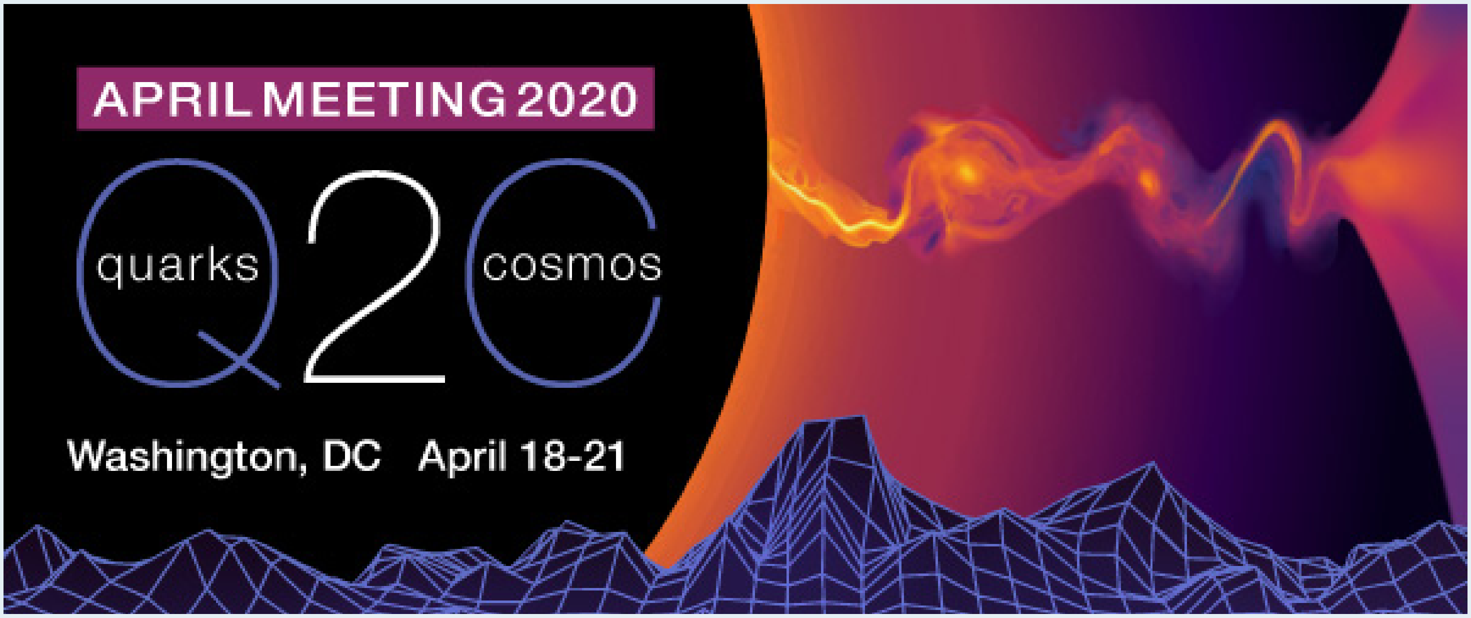
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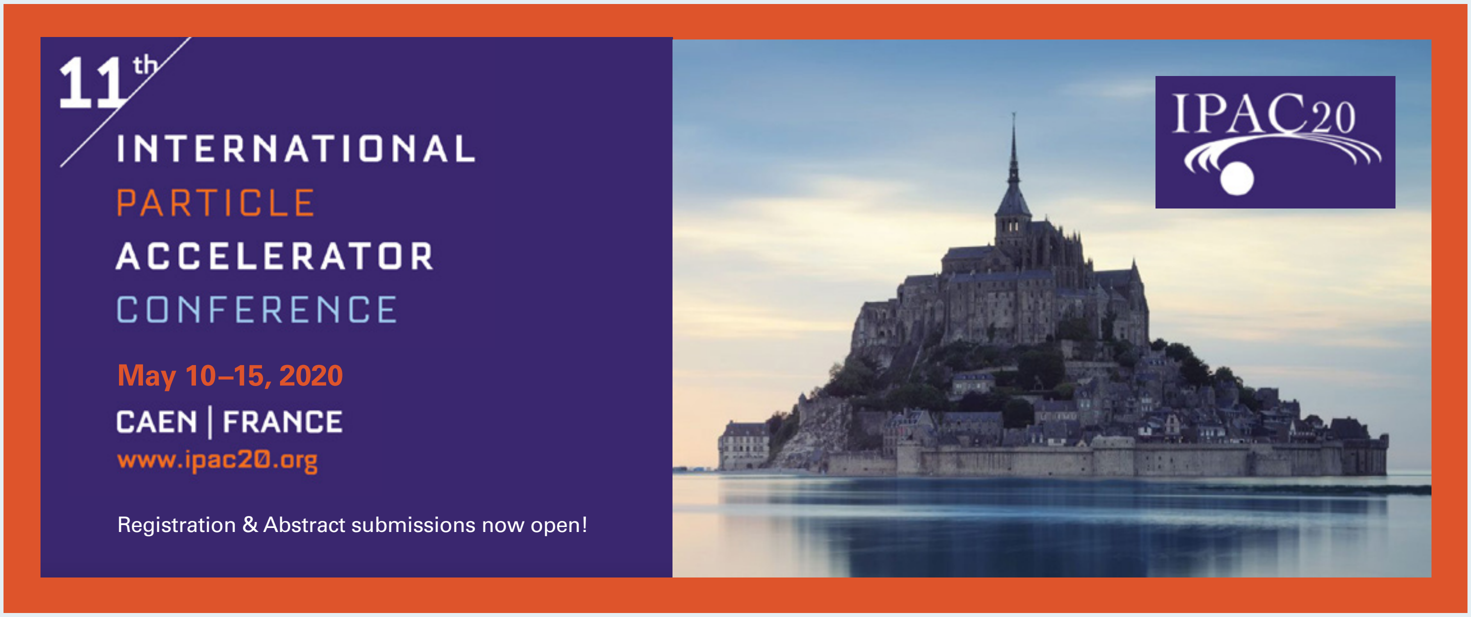
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First demonstration at Fermilab of conduction cooling for SCRF cavities:

A major step toward a compact superconducting accelerator for industrial applications

Charles Thangaraj, Ram Dhuley, Michael Geelhoed, Sam Posen *Fermi National Accelerator Laboratory*

Electron beam (EB) irradiation is a demonstrated technology capable of addressing several energy and environmental applications such as treatment of wastewater, sludge, and medical waste [1]. However, widespread adoption and application of high-power (meaning greater than 1 MW) EB irradiation is still lacking. A cost-effective technology to produce MW-class electron beams is therefore key to commercializing EB irradiation systems for environmental and industrial applications.

Exploiting recent advances in superconducting RF cavities and RF power sources, we at Fermilab have developed a design for a compact SRF high-average-power electron linac [2]. A cornerstone technology behind our SRF accelerator is a patented technique for cooling the superconducting RF cavity called conduction cooling [3]. This summer, our Fermilab team successfully operated a conduction-cooled SRF cavity and achieved an acceleration gradient of more than 6 MV/m at 650 MHz, sufficient for many applications.

All modern large-scale accelerators for physics research rely on SRF technology as an efficient means of transforming wall-plug electrical power into high-energy electron beams. The liquid helium cryogenics infrastructure, required for sustaining superconductivity, is a major driver of cost and complexity of such systems. While the cost and complexity of liquid-helium cryogenics can be justified for a large-scale accelerator, they can be cost-prohibitive and inconvenient operationally for accelerators intended for industrial applications. The liquid-helium systems are necessary because SRF accelerators are presently based on cavities made from pure niobium. Losses in such cavities result from thermal excitations that break electron Cooper pairs, the BCS surface resistance, which scales as a function of exp (-Tc /T), where the critical temperature Tc of pure Nb is 9.2 K, and T is the operating temperature. To achieve acceptable losses in continuous wave operation at reasonable accelerating gradients, pure Nb cavities must be operated at low temperatures, (e.g., ~2 K) and/or low frequencies, resulting in very expensive and complex accelerator cryomodules, large physical size, and refrigeration systems that require experts to operate.

Our unique approach to realizing an economical SRF accelerator for industrial application is to eliminate liquid helium and its support infrastructure from the accelerator and cool the cavities via conduction cooling. The required cryo-cooling can be provided by compact closed-cycle cryocoolers operating near 4 K. Substantial capital cost reduction is expected if the helium liquefaction plant, distribution system, and helium pressure vessel inside the cryomodule are removed.

At Fermilab, we demonstrated an experimental method based on ultra-low cryogenic heat load—Nb_3Sn-coated Nb cavities combined with conduction links to reduce the overall cryogenic load. This allows the creation of a very simple cryomodule in which the required refrigeration is supplied by reliable, commercial, sealed-system, 4 K cryocoolers. The cryocoolers can be turned on and off by pressing a button, have no liquid-cryogen-related safety hazards and have excellent reliability.

Fig. 1 shows a schematic of a proposed, fully-dressed accelerating structure comprising a 4.5 elliptical-cell SRF cavity conductively linked to the second stage of a two-stage cryocooler. The design includes a thermal shield around the cavity to intercept room-temperature thermal radiation, a fundamental RF power coupler and a vacuum vessel enclosing all the components. The cryocooler's first stage provides cooling (at ~60 K) for the thermal shield as well as the power coupler body.

Unlike a liquid-helium-cooled SRF structure that requires multiple cooling fluids and cooling loops at different temperatures (cavity, thermal shields), all the cooling is provided by a single compact cryocooler. The accelerating structure depicted in Fig. 1 is hence a standalone unit with all the cryocooling equipment housed within the structure and a commercial cryocooler directly attached to the structure.

Our experimental setup for successfully demonstrating the conduction-linked cooling of a single SRF cavity is shown in Fig. 2. Our mechanism of connecting the cavity to the thermal link involves welding niobium rings around the elliptical cells near the cavity's equator, where heat dissipation is expected to be maximum in an elliptical cell cavity. Our patented technique involves joining a high-purity aluminum thermal link to the cavity's niobium rings, optimized by systematic experimentation [3]. The niobium-niobium welds as well as the niobium-aluminum pressed contacts are sources of thermal resistance, which must be kept small. Our experimental data of thermal joint resistance has produced contacts with as small as 1 K•cm^2/W thermal resistance at 4.2 K [4].

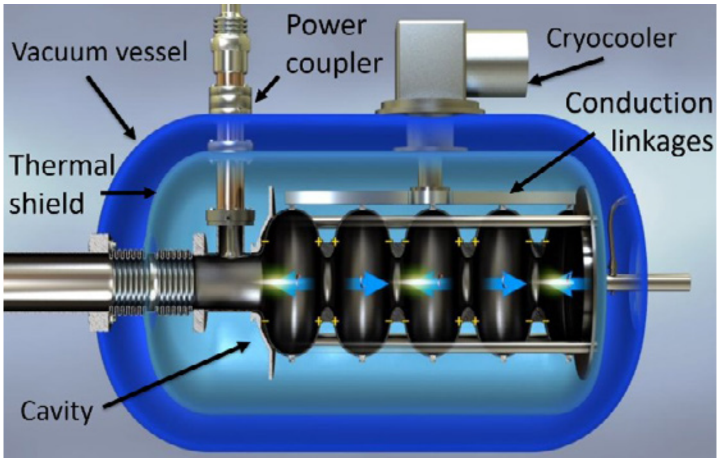


Figure 1. Schematic of a liquid-cryogen-free SRF accelerating structure. The SRF cavities are conductively cooled by a cryocooler. The cryocooler also provides cooling for the power coupler body and thermal shield. All the components except the cryocooler are housed inside a vacuum.

We have been able to drive RF power into the cavity and show a steady gradient of 6.6 MV/m in a single-cell, Nb_3Sn-coated 650 MHz cavity with a single cryocooler. Even though the gradient appears low compared to large machines, most industrial applications that we are aiming for require only 10 MeV of beam energy. Our R&D efforts will continue to push towards higher gradient and our goal is to reach 10 MV/m.

Because of the rapid record-breaking advancements in the reach of high Q_0 of Nb_3Sn cavities (now reaching accelerating fields as high as 23 MV/m) [5] and improved capacity of modern cryocoolers, it is possible for the first time for SRF cavities to be cooled via conduction using cryocooler vs. being immersed in a liquid helium bath and still operate at useful gradients. Most importantly, conduction cooling eliminates the need for large cryogenic refrigerators, pressure vessels, helium gas/liquid inventory management systems and expert operators. The overall result is a dramatic simplification in complexity and cost along with greatly improved reliability. Our results indicate that one can envision compact, turn-key SRF accelerator systems for industrial applications.

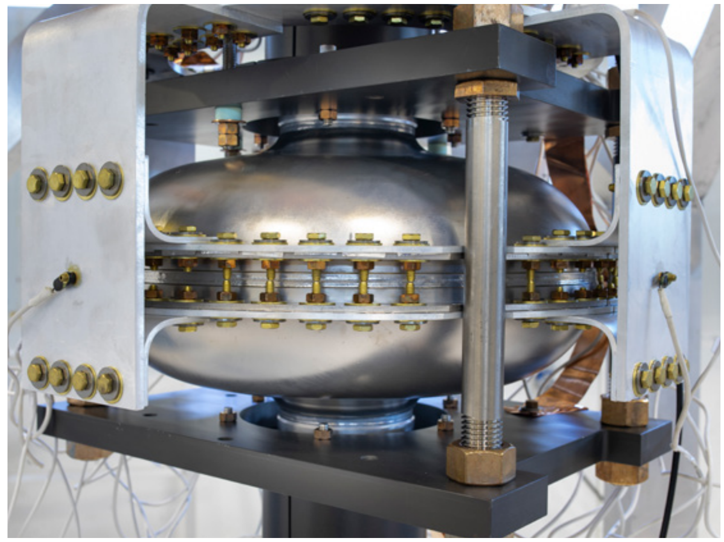


Figure 2. For the first time, a team at Fermilab has cooled and operated a superconducting RF cavity—a crucial component of superconducting particle accelerators—using cryogenic refrigerators, breaking the tradition of cooling cavities by immersing them in a bath of liquid helium. It achieved an accelerating gradient of 6.6 million volts per meter.

Charles Thangaraj is the science and technology manager at the Illinois Accelerator Research Center at Fermilab. The core team in this project included Ram Dhuley, Michael Geelhoed, Sam Posen and Charles Thangaraj. This project is supported by the Laboratory Directed Research and Development program at Fermilab. The work is also supported by the DOE Office of Science.

References

1 US Department of Energy "Workshop on Energy and Environmental Applications of Accelerators," (2015). Report available online at https://science.energy.gov/~/media/hep/pdf/accelerator-rd-stewardship/Energy_Environment_Report_Final.pdf

2 R. Kephart et. al., Proceedings of IPAC2017, Copenhagen (2017)

3 R. Kephart, "Conduction Cooling Systems for Linear Accelerator Cavities", Patent#US9642239B2

4 R. C. Dhuley, M. I. Geelhoed, J. C. T. Thangaraj, "Thermal resistance of pressed contacts of aluminum and niobium at liquid helium temperatures," Cryogenics, vol. 93, pp. 86-93, 2018. https://doi.org/10.1016/j.cryogenics.2018.06.003

5 S. Posen, et. al., "Nb_3Sn At Fermilab: Exploring Performance", Proceedings of 19th International Conference on RF Superconductivity, (2019).

The Future Trends in Electron Linacs for Industrial and Medical Applications

S. Boucher, S. Kutsaev and A. Murokh *RadiaBeam Technologies LLC*

This article is not a broad overview of the industrial and medical accelerator markets, but rather the personal vision of the authors on the current trends in developing multi-MeV-class electron accelerators for applications in industry, medicine and security. An industrial linac system generally incorporates a microwave power source, an accelerating structure with a thermionic electron gun attached and either a window for transmitting the electron beam outside the accelerator or an X-ray converter (aka "target"). Other common sub-components include shielding, scanning horn, focusing solenoid and other auxiliary system for which introduction generally depends on the application specifics. For the sake of this discussion, we consider an archetypical industrial linac about a meter long, accelerating an e-beam up to 10 MeV and generating up to 1 mA average current. It is powered by a 3–30 kW average power, 2–5 MW S-band (3 GHz) magnetron or klystron and would produce as much as 10 kW of beam power at the end of the linac. An optional bremsstrahlung target converts the electron beam power into broadband X-rays with about 5–10% efficiency. Without collimation or flattening filters, this would result in a cone beam with a peak dose rate of 10–100 Gy/min at one meter. The applications of such a linac include medical device sterilization, non-destructive industrial radiography, cargo inspection, radiotherapy, and a number of other niche applications across numerous disciplines.

Such linacs were originally developed in the 1960s, and they have not changed much since then. They are available basically off-the-shelf from more than a dozen companies with worldwide production output of over 1,000 units per year. The highest added value flagship application of such machine is medical radiotherapy, as is exemplified by the Varian medical linacs [1]. Below, we discuss directions in which industrial linac technology could evolve beyond this very successful, but also aging, model. In particular, we will discuss linac miniaturization, tailoring linac output for the needs of specific applications, reducing cost to achieve viability in new markets, and finally a longer-term transition from microwave to laser driven accelerator technology.

Miniaturization

There are many reasons to reduce the size and weight of the linac for specific applications. For example, security applications such as cargo inspection systems require the accelerator system to fit in a mobile platform. Likewise, compact medical linacs can allow more flexible access around the patient or aid configuration into novel image guided systems, such as the Viewray MRI-linac [2] or the Reflexion PET-linac [3]. Potential industrial applications of compact linacs include self-contained irradiators for research, blood and other niche applications, field radiography, borehole logging and safeguard tools, where radioactive isotopes are currently used. Such sources are being replaced with accelerators due to the risk of accidents and diversion by terrorists for use in dirty bombs. The main drivers of size and weight in conventional accelerators are the power source and the shielding. For a given dose, the shielding size and weight depends to an extent on the size of the accelerator within.

One approach to reduce the size of all these components is to utilize a high-frequency accelerator carefully optimized to minimize size, and to carefully design the rest of the system around it. Operation at high frequency has several advantages compared to low frequencies, as the effective shunt impedance (which defines power transfer efficiency to the beam) scales as f1/2 and dissipated power as 1/f1/2. The lower Q of high frequency systems also allows the filling time of the cavity to be shorter, reducing the amount of time during which power goes unused.

Thus, RF cavities operating at high frequencies require significantly less power than those operating at low frequencies. The choice of the optimal frequency depends on the required linac parameters and the availability of RF power sources. For example, C-band (6 GHz) provides the highest power capability in terms of magnetron power and cooling capacity due to the dimensions, and can be used for 9+ MeV machines. X-band (10 GHz) is a perfect choice for 4–6 MeV accelerators, while Ku-band (16 GHz) offer the smallest dimensions (Fig. 1), but can be used for sub-MeV to 4 MeV linacs since commercial magnetrons are only available for hundreds of kW power. Further frequency increase, for example to Ka-band (~35 GHz), is also possible. However, Ka-band magnetrons have comparable weight, size and power parameters as Ku-band magnetrons while the tolerance requirements and manufacturing complexity of 35 GHz structures will increase dramatically [4].

Another interesting option is to move to mm-wave frequencies such as W-band (100 GHz) and beyond. The advantage of higher frequencies is the potential ability to reach very high accelerating gradients (> 200 MV/m) [5]. However, the limiting factor for mm-wave accelerators is the absence of ns-scale RF power sources. Gyrotrons are the only power sources capable of producing the required (~100 kW) power levels in mm-wave, but they are not compact, and generate longer pulses at low repetition rates. However, a rapid development of the THz source technology may significantly improve the prospects for miniature W-band linacs within a decade [6].

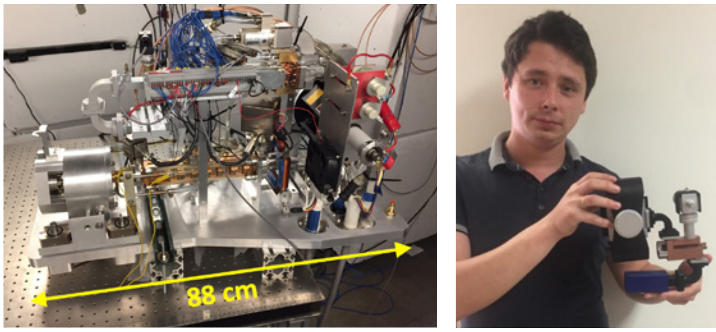


Figure 1. (Left) a compact X-band 6 MeV linac for radiation therapy; (Right) RadiaBeam's RF Engineer Dr. A. Smirnov holding a model of 200 keV Ku-band linac for Co-57 radioisotope replacement in Cascade Header Enrichment Monitor.

Finally, the most dramatic effort towards miniaturization of the industrial accelerator technology is being presently undertaken by the initiative funded by the Gordon and Betty Moore Foundation to utilize laser-driven acceleration in a dielectric periodic structure to develop a so called "accelerator on a chip" [7]. At the present time this is a multi-institutional R&D program that has demonstrated close to 1 GeV/m gradients; but a number of critical technical issues are yet to be resolved (i.e., injection, focusing, achieving high average current). With good momentum and a dynamic research community behind this initiative, it is important to acknowledge this work as approaching the ultimate frontier of linacs – miniaturization all the way to the optical frequencies.

Flexibility

Besides the need for miniaturization, another area of development in industrial linacs is flexibility. RadiaBeam has made a number of custom industrial linacs over the past few years with output tailored to match the needs of specific applications. In essence, the ideal linac to meet demands of the largest numbers of customers would have independently tunable current, beam energy and pulse profile over large dynamic ranges. Achieving such flexibility is relatively straight forward in an accelerator research lab, but at the same time it is far from trivial for an industrial system designed for a non-expert customer.

In one example (Fig. 2) for portal and rail cargo screening systems, RadiaBeam developed a linac with energy ramps within a single macropulse from 2 MeV to 9 MeV in 400 ns intervals [8]. This linac enables adaptive material discrimination within a single pulse, and in principle could be reconfigured for other applications requiring energy modulation within a single pulse.

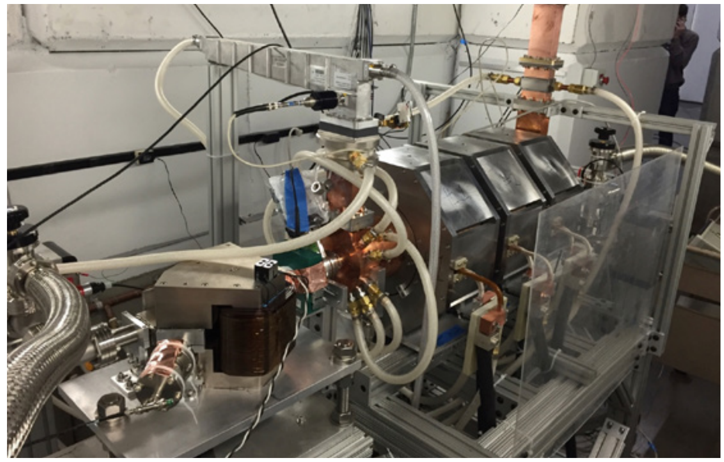


Figure 2. Highly-flexible linac for cargo inspection that can produce a 2-9 MeV energy ramp within a 16 μs macropulse.

Another technical area where there is a need for a flexible, widely varying yet well controlled and calibrated output is space systems for radiation hardened electronics testing. RadiaBeam has been developing conventional S-band linacs customized for this application and also been involved into the development of a plasma wakefield system designed to mimic more accurately the exponential energy distribution of the space radiation background [9].

Low cost market problem

Generally, we want to make linacs better not cheaper, and in most of the mature markets they are already cheap enough compared to the cost of the complete systems or operations. Some newer market segments, however, require cost reduction for economic viability. For example:

- Low power/low energy linacs for radiography and self-contained irradiators need to be affordable to replace currently used radioisotope irradiators
- Low and Middle Income Country (LMIC) radiotherapy markets
- High-throughput applications, such as food irradiation, water purification and other environmental processes require reduced operational costs and maximized energy efficiency to meet market demands.

One way to address the capital cost challenge is to take advantage of new manufacturing processes such as additive manufacturing and micromachining. RadiaBeam has been actively involved for over a decade in development and optimization of the 3D-printing process in copper and niobium, using electron beam melting [10] with the ultimate goal to develop capabilities to build layer-by-layer accelerating structures and components. Another interesting approach is to use a novel "split-structure" design of the linac [11]. Instead of machining dozens of precise, individual cells that must then be brazed together and tuned, with this approach the RF structure consists of just two blocks of copper with a pattern micro-machined into the surface; the two halves are then joined (either welded, brazed or diffusion bonded). This achieves greater precision at lower cost, reduces part count, avoids braze joints on sensitive RF features and potentially eliminates the need for tuning. Split linac structures and additively manufactured structures could potentially become much cheaper than conventionally fabricated linacs and in the long run open up new markets.

Finally, we note that for high-throughput applications, the emerging superconducting industrial linac technology has the potential to significantly increase the duty cycle and therefore power output of the linacs by eliminating the RF power dissipation in the structure. In recent years, the development of self-contained Gifford-McMahon and pulse tube refrigerators have continued to improve in both reliability and capacity. The cooling capacity of these systems has become great enough to consider their application for cooling SRF resonators and associated components. Such systems are of interest both to scientific facilities and for industrial applications as they do not require massive and extremely expensive cryogenic facilities (4.4 K) and the trained specialists required for their operation. Stand-alone accelerators can be used as bunchers or accelerating sections in large accelerator facilities or as turn-key accelerator systems for industrial applications such as materials processing, semiconductor manufacturing, food irradiation and homeland security [12]. Recent innovations in Nb_3Sn cavities [13] allow use of cryocoolers and conduction cooling of the cavity, which simplifies the design and reduces the cost of the accelerator.

Laser-driven systems

Finally, as the advanced accelerator technology develops in universities and national laboratories, some of these new types of accelerators may be able to replace some linacs for industrial and medical applications. These new concepts include dielectric laser accelerator [2], laser-plasma-accelerators (LPA) [4,14], inverse-free electron lasers [15], plasma-wakefield accelerators [16], as well as new light source concepts such as plasma betatron radiation, and inverse Compton scattering radiation. Although more detailed discussion of these novel methods is outside the scope of this manuscript, we note that all these methods take advantage of the rapidly improving ultrafast laser technology and in the long run have a potential to disrupt many existing and emerging market segments presently relying on more conventional linear accelerator technology.

References

1 www.varian.com

2 www.viewray.com

3 www.reflexion.com

4 S.V. Kutsaev et al., "Sub-MeV Ultra-Compact Linac for Radioactive Isotope Sources Replacement, Non-Destructive Testing, Security and Medical Applications", Nuclear Inst. and Methods in Physics Research, B, vol. 459, pp. 179-187 (2019).

5 M. Dal Forno et al,, "RF breakdown tests of mmwave metallic accelerating structures", Phys. Rev. Accel. Beams 19, 011301 (2016).

6 S.V. Kutsaev et al., "Nanosecond rf-Power Switch for Gyrotron-Driven Millimeter-Wave Accelerators", Phys. Rev. Applied 11, 034052 (2019).

7 https://achip.stanford.edu/news

8 S. Kutsaev et al.,, "Electron Accelerators for Novel Cargo Inspection Methods," Physics Proc. 90, 115-125 (2017).

9 B. Hidding et al., "Laser-plasma-based Space Radiation Reproduction in the Laboratory," Sci. Rep. 7 (2017). https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5296722/pdf/srep42354.pdf

10 R. Frigola et al., "Fabricating copper components with electron beam melting," Adv. Mater. Processes 172(7), 20–24 (2014).

11 H. Zha, A. Grudiev, V. Dolgashev, "RF design of the CLIC structure prototype optimized for manufacturing from two halves", in: Proceedings of IPAC2015, Richmond, VA, USA.

12 R. Kephart et. al., "SRF, Compact Accelerators For. Industry & Society," FRBA03 Proceedings of SRF2015,. Whistler, Ca (2015).

13 S. Posen and D.L. Hall, "Nb_3Sn superconducting radiofrequency cavities: fabrication, results, properties, and prospects," Superconductor Science and Technology, 30 (2017) 033004.

14 https://bella.lbl.gov/laser-plasma-accelerators-background-and-motivation/

15 J. Duris, et al., "High gradient inverse free electron laser acceleration in helical geometry," Nature Communications, 5, 4928 (2014).

16 https://royalsocietypublishing.org/doi/10.1098/rsta.2019.0215

University Spotlight: Michigan State University

Peter Ostroumov *Michigan State University*

On September 25, 2017, the U.S. Department of Energy's Office of High Energy Physics awarded Michigan State University a five-year Accelerator Science and Engineering (AS&E) traineeship cooperative agreement to train domestic graduate students in four areas of emphasis to meet future workforce needs: (1) physics and engineering of large accelerators; (2) superconducting RF (SRF) accelerator physics and engineering; (3) RF power engineering and (4) large-scale cryogenic systems.

The MSU Accelerator Science and Engineering Traineeship (ASET) program is fully established now, and it is based upon MSU's strengths to formulate a graduate student curriculum that is being implemented by faculty members within the College of Natural Science Department of Physics and Astronomy, the College of Engineering Department of Electrical and Computer Engineering; Mechanical Engineering; and Computational Mathematics, Science, and Engineering, and the Facility for Rare Isotope Beams (FRIB). This program exploits the world-leading research conducted at MSU to train the next generation of scientists and engineers needed to maintain the scientific and technological leadership of the United States in these areas of critical need. The ASET program is part of the university's top-ranked nuclear physics graduate program, according to the U.S. News & World Report's rankings of graduate schools. After startups the ASET program will produce five to seven MSU graduates per year in the critical areas of workforce need. ASET is leveraging unique campus-based capabilities at FRIB, extensive AS&E faculty, scientists at MSU and FRIB, and resources at our partnering DOE national laboratories to create a new and unique program to produce students with competence in AS&E. Details of the ASET program are described in the dedicated website https://www.frib.msu.edu/science/ase/graduate-studies.html.

Students in the ASET program are being trained and mentored by more than 20 MSU and FRIB faculty members. In addition, more than 30 Ph.D. scientists and engineers working in ASET areas at FRIB are mentoring students to enhance their experience. The partnerships with DOE laboratories will integrate ASET students into their research program beyond the third year and support them until the completion of their theses. The Accelerator Traineeship Advisory Panel is a national advisory committee established nearly two years ago to help guide the program. The MSU Cryogenic Initiative (https://www.frib.msu.edu/science/ase/cryogenic/index.html) supports training of ASET students in large-scale cryogenic systems, cutting-edge technologies and advancements in the cryogenic field.

Many ASET students supplement MSU courses through participation in the U.S. Particle Accelerator School.

Currently, there are 15 graduate students are being trained under the ASET program pursuing their training and research in all four workforce-needs areas. After the first year of graduate studies, the ASET students have an opportunity for a summer internship in DOE national laboratories. The first ASET student, Crispin Contreras, received a Fermilab's Ph.D. fellowship and works on development of superconducting resonators for medium-velocity hadron accelerators at Fermilab. Another ASET student, Michael Balcewicz, is at Brookhaven National Laboratory to work on his thesis research related to hadron beam instabilities in circular colliders. Additional lab placements are pending. Upon completion of the program, students receive an ASET certification and will be specialists in one of four critical workforce-needs areas.

The current ASET/FRIB faculty includes professors, and adjunct professors in the College of Natural Science (Department of Physics and Astronomy) and the College of Engineering (Departments of Electrical and Computer Engineering and Mechanical Engineering). As of June 5, 2019, 21 graduate students including 15 ASET students are being trained in the area of Accelerator Science and Engineering by the FRIB Accelerator System Division (ASD) and ASET Faculty. In addition, 31 physics and engineering undergraduate students gain experience working as technical assistants during the summer.

ASET Faculty Research Profile

Associate Professor Sergey Baryshev

Department: Electrical and Computer Engineering

Expertise: High-brightness electron source for linear accelerators and pulsed power systems, time-resolved microscopy, superconductivity, applied surface science.

Current research combines materials science, accelerator technology, and microscopy. Specifically, he focuses on novel field- and photo-emitter materials and designs for accelerator and detector R&D; physics of breakdown; diamond materials for high power and high frequency applications; and transmission and scanning electron microscopy, including time-resolved methods, for materials science and electronics.

Professor Venkatarao (Rao) Ganni (joint FRIB appointment)
Department: Mechanical Engineering

Expertise: Thermodynamic principles and theories applied to cryogenic cycles, cryogenic systems and the related component development. Most of his research topics have been in the applied sciences related to cryogenic systems and they include thermodynamic exergy studies, heat exchangers, turbo machinery, screw compressors, sub-atmospheric pumping systems, control theories and instrumentation for these systems.

Current research: Development of sub-system components required for small-scale 2 K helium refrigeration systems, freeze-out purifiers for helium gas purification, and a controlled cool-down and warmup system for the FRIB fragment separator area magnets.

Associate Professor Yue Hao (joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Nonlinear beam dynamics in charged particle accelerators including beam-beam effects in colliders, nonlinear beam transport, dynamic aperture; collective instability; free electron lasers; modeling and beam tuning in accelerator complexes; high-performance computing for accelerator physics.

Current research interests are in three major areas: nonlinear dynamics, high performance computing and statistical learning.

Professor Masanori Ikegami (adjunct and joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Commissioning of hadron accelerators; dynamics of high intensity hadron beams; distributed real-time control systems for large accelerators.

Current research is focused on commissioning and achieving design beam parameters in a high-power, heavy-ion accelerator; development of data visualization and controls tools in the EPICS software control system; development of highly reliable personal protection systems for large accelerators.

Professor Steven Lidia (adjunct and joint FRIB appointment)
Department: Physics and Astronomy; Electrical and Computer Engineering

Expertise: Broad field of accelerator science and engineering including high-power free electron lasers; self-amplification of spontaneous emission in FELs; high-current, low-emittance electron guns; simulations of space charge dominated beams; interaction of low-energy ion beams with plasma; beam diagnostics and instrumentation for high intensity ion beams.

Current research is focused on development of diagnostic techniques and advanced instrumentation for multi-species heavy ion accelerators; measurements to understand the behavior of intense, multi-charge state ion beams; high sensitivity and high speed sensors and networks for beam loss monitoring and development of electronics, firmware, and software to interface with these sensors; accurate beam profile monitoring and tomography; non-invasive beam profile measurement techniques; prediction and measurement of beam instabilities.

Professor Steve Lund (joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Theoretical accelerator physics emphasizing analytic theory and numerical modeling; high intensity beam dynamics, modeling and simulation of space charge effects including collective instabilities. A common theme in his research is to identify, understand, and control processes that can degrade the quality of the beam by increasing phase-space area or that can drive particle losses.

Current research is focused on charged particle dynamics, electromagnetic theory and numerical modeling in support of FRIB and post-target traps. Professor Lund is a passionate educator and as director of the U.S. Particle Accelerator School provides an outstanding contribution to the community by training and educating current and future accelerator scientists and engineers.

Professor Guillaume Machicoane (adjunct and joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Ion and electron sources; electron cyclotron resonance ion sources; plasma physics; beam dynamics.

Current research interest is the production of high current highly charged heavy ions in superconducting ECR sources; study of ECR ion source parameter space to avoid internal ECR plasma instabilities for long-term stable operation.

Professor Felix Marti (emeritus and joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Physics and engineering of normal and superconducting cyclotrons; beam dynamics, design and characterization of large magnets; stripping of ion beams.

Current research is focused on development of novel techniques for the stripping of high-power ion beams and plasma plugs for gas strappers.

Professor Ali Nassiri (adjunct; Argonne National Lab)
Department: Electrical and Computer Engineering

Expertise: electron accelerators including low-emittance electron guns, accelerating structures, high-power and low-level RF systems; RF power couplers; timing and synchronization.

Current research is being conducted in collaboration with national and international researchers on femtosecond timing and synchronization; development and testing of normal-conducting and superconducting crab cavities and associated RF control systems, design and application of advanced technologies for fabrication of novel RF structures; development of high power IOTs for accelerators; support of design and construction of Advanced Photon Source upgrade project.

Professor Peter Ostroumov (joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Accelerator physics and technology for large accelerators; application of RF superconductivity for accelerators; development of RF structures for acceleration and manipulation of stable and radioactive ion beams.

Current research interests include commissioning of FRIB driver linac, development of FRIB improvement and upgrade options including linac energy upgrade up to 400 MeV/u for heaviest ions and extension of FRIB's scientific reach by adding new accelerators, storage rings and electron-radioactive-ion and gamma-ray-radioactive-ion colliders.

Professor Kenji Saito (joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Superconducting radio frequency science and engineering for accelerators. Advanced technologies for the development of superconducting resonators including material selection, RF surface preparation and cold/RF testing.

Current research is focused on practical tasks to achieve design performance of SRF systems installed at FRIB and development of high performance SRF resonators with increased quality factor and high accelerating gradients for continuous wave operation.

Professor Sami Tantawi (adjunct, professor at Stanford University)
Department: Electrical and Computer Engineering

Expertise: Applied electrodynamics; high gradient accelerating structures; high power microwave systems; high power rf sources and pulse compression; microwave transmission lines.

Current research covers many areas such as high-power microwave systems, high gradient accelerating structures for next generation linear colliders; development of novel solid-state microwave devices and circuits; new passive RF components and novel vacuum electronics; theoretical and experimental development of microwave pulse compression and transport systems for the next Linear Collider Test Accelerator; development of novel solid state RF sources; and theoretical and experimental studies of RF breakdown phenomena.

Professor John Verboncoeur
Department: Electrical and Computer Engineering

Expertise: Theoretical and computational plasma physics, with applications spanning from: (a) low-temperature plasmas for lighting, thrusters and materials processing to hot plasmas for fusion; (b) ultra-cold plasmas to particle accelerators; (c) charged particle beams to pulsed power sources; (d) intense kinetic non-equilibrium plasmas to high-power microwaves.

Current research is focused on theoretical and computational plasma physics research, including algorithm, model, and code development with a broad range of applications.

Professor Jie Wei (joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Accelerator physics of high-energy colliders and high-intensity proton accelerators; beam dynamics of non-adiabatic regime and transition crossing in high-intensity rings and proton drivers; magnetic fringe field and nonlinearity correction; electron cloud formation and mitigation in high-intensity rings; intra-beam scattering of heavy-ion beams in colliders; beam cooling and crystallization; development of spallation neutron sources; development of compact pulsed hadron sources; development of hadron therapy facilities; development of accelerator driven sub-critical reactor programs for thorium energy utilization and nuclear waste transmutation; and development of accelerators for rare isotope beams.

Current research is focused on commissioning and operation of large accelerator systems such as FRIB.

Professor Vyacheslav P. Yakovlev (adjunct; Fermilab)
Department: Physics and Astronomy

Expertise: Development, design, construction and testing of SRF systems for large linear accelerators, applied electrodynamics, dynamics of high intensity beams, beam cavity- interaction, RT RF and SRF acceleration cavities and structures, high-power RF sources, industrial accelerators.

Current research is focused on development of large cryomodules and their sub-components (cavities, tuners, RF couplers) for modern SRF accelerators.

Professor Yoshishige Yamazaki (joint FRIB appointment)
Department: Physics and Astronomy

Expertise: Extensive experience in the design, construction and operation of large high-power hadron accelerators; advanced management skills.

Current research interest is in development and commissioning of large, superconducting accelerators; RF systems for normal conducting and superconducting accelerating structures; and high quality magnet systems for focusing and transport of ion beams.

Evolution of the US Particle Accelerator School: Status & Directions

Steven M. Lund, Director, USPAS *Michigan State University and Fermi National Accelerator Laboratory*

The U.S. Particle Accelerator School (USPAS) is a national, graduate-level program that provides training and workforce development in the science and technology of charged particle accelerators. As described in the companion article, "Historical Perspective of USPAS" by our manager Susan Winchester, the school has existed for nearly 40 years and has steadily improved within a fairly constant format since 1991. The USPAS should not be confused with a workshop or seminar series. We are an academically rigorous school that seeks to give a graduate-level experience consistent with major research and development universities. Our model is "old school," with much expected of students on challenging topics that are not typically offered in universities. Courses range from physics to engineering across a broad range of topics chosen to reflect our ever-evolving field. We offer courses that are broad introductory surveys as well as in an evolving collection of focus areas. Despite long hours, hard work and grades, typical students vote with their feet and return to our sessions approximately 3 times. Students often make connections in sessions that last over the duration of their careers, both with the instructors and their fellow classmates. A broad variety of students attend the USPAS from universities, laboratories, private companies, medical facilities, government and the military. Student backgrounds range from beginning graduate and undergraduate students in universities to experienced scientists and engineers.

Courses have helped train many luminaries and high performers in accelerator science and technology. Projects, conferences, and workshops are all well represented by our former students and our instructors—providing a testament to the impact of the school. Course materials are often archived on the USPAS website and have become resources in many accelerator subfields. Numerous advanced textbooks have evolved from USPAS courses to alleviate previous long-running documentation issues. Instructors often clarify and stimulate new areas.

Format

USPAS sessions are held twice a year (in January and June) for two weeks. Session locations are distributed around the country and are selected for proximity to accelerator labs and facilities. In each session, we typically offer 10–14 academically rigorous, university-style classes on physics and engineering topics that are taught by recognized leaders of the field. Classes can be full two-weeks (e.g., Accelerator Fundamentals, Accelerator Physics, Microwave Measurements Lab, Classical Mechanics and Electromagnetism for Accelerators, Synchrotron Radiation and FELs, RF Cavity Design, Space-Charge Effects, Numerical Simulation of Beams, etc.) or one-week short classes (e.g., Radiation Damage of Materials and Electronics, Vacuum Science and Technology, Cryogenic Engineering, Pulse Power Engineering, High Brightness Electron Injectors, Magnetic Systems, Engineering of Superconducting RF Accelerators, Cyclotrons, etc.). One-week classes are typically taken in pairs. The two-week classes Fundamentals and Accelerator Physics are offered every session, while other core classes like Microwave Measurement Lab and Classical Mechanics and Electromagnetism for Accelerators are offered approximately every year and a half. A plethora of one- and two-week specialty classes emphasizing different topics of focus repeat on a two- to four-year cycle. Both courses offered and the content of courses evolve with changes in the field. Total enrollment in the sessions typically ranges from 110–160 students with 30–40 instructors, teaching assistants and graders. Sessions are organized to enhance connections to regional labs to help stimulate interest and attendance. When possible, tours of a nearby accelerator lab are given on the middle weekend of the session.

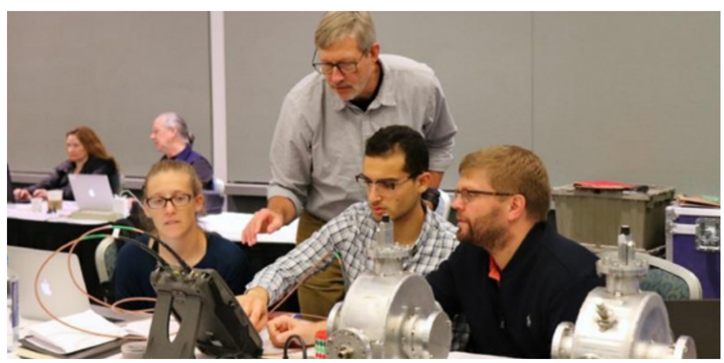


Figure 1. USPAS Instructor Elvin Harms with students in the Fundamentals class laboratory.

USPAS courses are typically not available in standard university curricula. The intensive format allows students to achieve competency in a short period of time with minimal interference with their academic studies, research, project work and family constraints. In spite of this session brevity, hours of student engagement with faculty and assistants in USPAS courses significantly exceed those of typical three-semester-hour university courses. This gives an

Figure 2. USPAS tour group at the Spallation Neutron Source in Winter 2019 at Oak Ridge National Laboratory.

intense but rewarding experience. Although our pace is difficult to sustain, we find that most students can thrive in an intense two-week interval. Every USPAS course has a web page description stating the purpose and audience, prerequisites, objectives, instructional methods, course contents, and reading and credit requirements. Outside of exams, students are typically encouraged to help each other, which helps further stimulate professional contacts that can last over a career. Instructors and teaching assistants are available for help with daily homework sets and projects.

Instructors take a significant load in preparing their courses within the intensive format. Due to this and the long days required, we encourage the use of teaching teams who coordinate via a lead instructor. Teaching for the school has become regarded as a professional accolade. Our instructors are eager to help educate the next generation to advance the field. This allows us to select luminaries and strong performers for our instructors. High quality instruction by well-regarded teaching teams helps us attract high-performing students, raising the level and impact of the school. The USPAS does not have a budget sufficient to pay for course preparation. Time of our instructors is largely donated in an altruistic sense of community service. Instructors find that teaching improves their own research and command of their topics. Such benefits help offset the load to prepare to teach and deliver a course under the intensive format. Most instructors are enthusiastic to continue teaching their topics until precluded by duties linked to promotions or deep retirement.

USPAS is funded by the U.S. Department of Energy's Office of High Energy Physics, which supports accelerator science and technology as a service to the field. The school's administrative office is based at Fermilab. We are advised by a collaboration of 10 DOE national laboratories and universities with active programs in accelerators. Our Directors Advisory Council is drawn from all USPAS collaboration members and meets yearly for strategic input on the school, and a Curriculum Committee meets twice yearly to review courses. This organization helps ensure that the USPAS delivers training meeting the diverse needs of the accelerator science and technology community.

Major research universities sponsor each session and provide credit for our USPAS courses. Eligible students can earn university credit by successfully completing the course requirements, which include lectures, problem sets and exams. Each sponsor university vets instructors and course offerings, grants academic credit and maintains student transcripts. Some universities—including Indiana University, Michigan State University, MIT and more on the horizon—are set up to directly convey credit for our courses to their students. This trend toward direct credit transfer helps further integrate the USPAS curriculum with R&D universities.

To attend our sessions, students pay a registration fee that covers course fees, materials, daily breakfast and dinner); housing costs (it is possible to share to reduce cost) and travel expenses. The group meals help increase efficiency of the sessions and increase technical interaction and contacts. We offer financial support to both undergraduate and graduate students, and postdocs within 5 years of graduation.

Future Directions

USPAS has benefited from many years of effective management by our local office staff and former directors. The school is on a sound footing due to gradual evolutionary improvements made over many years. No major changes are presently necessary. However, we actively seek opportunities to refine our model and deliver the highest quality training possible. Change is essential to meet the needs of our ever-evolving field. Recent points of emphasis include:

- Using of larger teaching teams mixing experienced instructors with early career members, seeking to have team members—and particularly lead instructors—with prior USPAS experience so there is awareness of the specific demands of the intensive USPAS format.
- Encouraging classes to post and maintain materials long-term on web sites as a community resource, even going beyond the scope of what can be covered in the course.
- Selecting courses that support regional activities near the venue.
- Improving the USPAS website and governance organization to better serve the field.

The use of larger teaching teams stimulates connections to recruit more students, helps avoid schedule constraint issues for a multitude of professional and personal reasons, and gives more people the benefit of a teaching experience.

Linking session topics to regional labs furthers local connections to the school to enhance turnout and gives the community a sense that the school serves their projects. These strategies of larger teaching teams and enhanced regional contacts appear to be paying off with increased enrollment. Our 2019 winter and summer sessions had 338 total students—our second highest count in the school's 40-year history.

Finally, the school has been improving our website and school governance to enhance our interaction with the community and ensure that our courses properly reflect the evolution of the field and future directions. Efforts are being made to better represent industrial and medical interests in the USPAS curriculum to reflect the increasing attraction of these options with our students.

Recent government reports indicate looming shortages of accelerator specialists to both staff present facilities going forward as well as serve future directions in discovery science and high technology that are vital to the future economy. Due to this, DOE has rolled out traineeships to fund more students to enter the field in key need areas. The first traineeship was awarded to Michigan State University in 2017, two more traineeships have been founded in 2019: the "Chicagoland" traineeship linked to Illinois Institute of Technology and Northern Illinois University, and the "Courant" traineeship linked to Stony Brook University and Cornell University. USPAS will work closely with all traineeships to help meet program needs. Additionally the USPAS is working with Indiana University to recruit students for the IU/USPAS master's program. This highly economical program has been effective at increasing training of accelerator operators at national laboratories. Careful management of finances has allowed the USPAS to simplify our student scholarship policy allowing now all students to be eligible to receive scholarships (registration fee plus board and shared housing, but not travel). The APS Division of Physics of Beams has also worked with the USPAS to roll out a new travel support scholarship effective every session which will likely support up to nine awards per session. This program will also encourage students to join APS DPB to help meet long-term division membership goals that are important to our community. Industrial partners are also increasing their support of courses and student scholarships. All together, these various programs and changes should stimulate session attendance to maintain our present high student counts and serve pressing workforce training needs in the field.

To better quantify hiring needs in our field and support our selection of specific courses and repetition periods, the USPAS has begun working with the 10 collaborating labs to sample yearly hiring by topic. Preliminary data for 2019 indicates an excess of 220 jobs in areas consistent with training we provide. This sample does not include industry. We envision gathering this data yearly and extending the methodology to better quantify community needs for USPAS, DOE, traineeships and accelerator serving institutions.

U.S. Particle Accelerator School:
Education in Beam Physics and Accelerator Technology

uspas.fnal.gov

Summer 2020 USPAS Session
June 15-26, 2020

Sponsor: Stony Brook University
Location: Melville, Long Island, New York

Participation is open to both U.S. and non-U.S. citizens. International participants not currently residing in the U.S. may apply to attend the program and may request financial sponsorship but they may not earn credit from Stony Brook University.

Scholarships should be requested on our Application Form and are due by March 11, 2020. In addition to the application form please submit a cover letter explaining why the USPAS is important to your career and describing prior research experience, work with or as a user of particle accelerators; your CV; one letter of recommendation. All of these documents should be emailed to uspas@fnal.gov. USPAS scholarships are awarded without regard to race, gender, sexual orientation or national origin. Consideration will be given to balancing class sizes.

Travel scholarships: The Division of Physics of Beams (DPB) of the American Physical Society is offering a limited number of travel scholarships to USPAS students. Applicants must be members of the DPB (note that student membership is free for the first year). The DPB scholarship will cover travel expenses and your USPAS scholarship will cover housing and your registration fee. Scholarship amounts will vary based on points of travel origin. These scholarships are open to domestic and international students who meet the usual USPAS scholarship requirements (required documents listed above). You can enroll for DPB membership at https://www.aps.org/membership/ and more details on eligibility and the selection criteria can be found at the DPB Scholarship Details link https://uspas.fnal.gov/dpbscholarshipdetails.pdf. Note that DPB membership will be verified prior to an applicant being considered.

Deadline for scholarship requests: March 11, 2020
Deadline for lower registration fee: April 1, 2020

Historical Perspective of USPAS

Susan Winchester, Manager, USPAS *Fermi National Accelerator Laboratory*

When Mel Month organized the first "U.S. Summer School on High-Energy Particle Accelerators" back in 1981, I don't think he had any inkling of the prominence this program would attain in the field of accelerator physics. The earliest symposium-style sessions were organized with many lectures given over a two-week period held at either Fermilab, SLAC or Brookhaven National Lab. Though the first eight sessions were very well received, Mel wanted something more rigorous. In 1984, he asked the directors of Brookhaven, SLAC, Fermilab, CEBAF and the Cornell University Lab of Nuclear Studies to form a steering committee to advise him on how to structure a formal training program in the development, operation and use of accelerators. Such courses were not commonly taught in universities—people had to learn them on their own or on the job. Mel intended to change that.

At the same time, Mel created the APS Topical Group on the Physics of Beams, which would later become the Division of Physics of Beams. He also initiated the USPAS Prize for Achievement in Accelerator Physics and Technology and the Joint US-CERN International Accelerator School. He was a busy guy.

In 1986, encouraged by the early success of the program, Mel changed our name to the U.S. Particle Accelerator School, formed the USPAS Program Advisory Committee (now the Curriculum Committee) and approached the physics department of the University of Chicago with a proposal for a new university-style program of courses that would carry university credit. After months of negotiations, the university agreed. Over a four-week period during the summer of 1987, we organized our first university-style school in conjunction with what would become one of our last symposium-style schools. It became immediately clear to us that people were very interested in the new credit courses. Although USPAS offered only four classes that first year, the enrollment in each was much higher than anyone expected. At the same time, the paired symposium-style session was much smaller than usual. Our attendees were voting with their feet. In 1989, after one more symposium school, USPAS discontinued the symposium series to concentrate on our for-credit courses. We never looked back.

The popularity of the school continued to grow, and many of the early university-style schools were very large. So large, that in the early '90s we increased from one session each year to two per year in the hopes of spreading out the attendance and having smaller, more manageable sessions and classes. Mel chose to hold one school in June, when he thought it would be easier for university students to attend, and one in January, when it might be easier for lab employees to take two weeks away from their families. But instead of splitting the 150 students into two smaller sessions as intended, the attendance at the school literally doubled, with 150 students at each session.

Figure 1. The first USPAS team: Marilyn Paul, Mel Month, and Susan Winchester.

In the mid-'90s, USPAS offered its first hands-on course in RF measurements at the MIT Bates Lab. Students gained experience at an operating accelerator using real equipment. This course became the prototype for future USPAS courses offering benchtop experiments necessary for accelerator-related measurements and operational experience with accelerator systems and beam measurements. RF measurements quickly became one of our core offerings, and we have been extremely fortunate that companies like Hewlett Packard, Agilent, Keysight Technologies, Rohde & Schwarz and National Instruments have all loaned us equipment, giving our students hands-on experience with contemporary, top-of-the-line instrumentation.

Along the way, many instructors wrote textbooks based on their USPAS courses—in the early days as a part of the Wiley Series in Beam Physics and Accelerator Technology—textbooks that we continue to use today. We recently created a new carousel of books based on and inspired by USPAS courses on our website. We may have missed some, but we are proud to have 16 textbooks in that carousel. A huge achievement!

The basics haven't changed much since that first university-style school in 1987: Each full, two-week course still has at least 45 instructor contact hours and still earns the equivalent of three semester hours of university credit. Our courses still include lectures, homework, exams and class projects. We've increased the number of classes offered at each session, and we introduced one-week, half courses to appeal to people who want more focused specialty topics or can't be gone from their jobs for two weeks—all consistent with Mel's early vision.

Almost 40 years later, USPAS is bigger and better than ever. Our recent summer session with the University of New Mexico was one of our largest sessions ever.

In addition to Mel, we've been incredibly lucky to have four other outstanding directors. Each one has left a lasting mark on USPAS. S.Y. Lee succeeded Mel and was the architect behind many features of the School that are essential to our continued success. S.Y. was the driving force behind the Indiana University/USPAS Master's Degree in Accelerator Physics and Technology program that allows a student to earn a master's degree from Indiana University by attending USPAS courses. Our master's program appeals to people who are working and cannot attend a university full-time. Seventeen master's degrees have been awarded since the program began, and we currently have 12 students enrolled. Because of this program, IU was the first university to co-list all USPAS courses so IU students could directly receive IU credit from USPAS courses taken. Now, in addition to IU, Michigan State University and MIT also co-list our courses, and we are working with several other universities to grant home-university credit to their students as well. This approach eliminates the need for students to transfer their USPAS credits. S.Y. also created our first computer lab, now a mainstay of our sessions, and designed and maintained our first website. Because he wanted our course materials to be available even to students who were unable to attend in person, he created an area on our website for class lecture notes and materials. You won't be surprised to learn that this is the most visited page on our website.

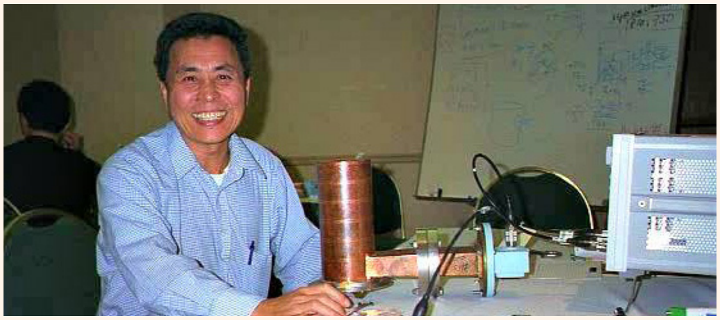


Figure 2. S.Y. Lee.

Figure 3. Helmut Wiedemann, Mel Month, and Bill Barletta.

Our third director, Helmut Wiedemann, designed and built one of the crown jewels in our program: the hands-on experimental labs in our undergraduate-level Fundamentals of Accelerator Physics and Technology with Simulations and Measurements Lab class. Helmut begged and borrowed equipment to create experiments that cover a wide swath of procedures used on actual accelerators. He brought in everyday items like popcorn and cookie tins to demonstrate aspects of RF cavities. Along the way we added more realistic cavities for other experiments. We are continuously upgrading the labs, and we occasionally purchase state-of-the-art instruments so that student can learn with equipment being used back at their home institutions—signal generators, digital oscilloscopes, spectrum analyzers, etc. The labs are always being updated and improved. Heavy positioner tables and makeshift plexiglass probe holders have been replaced with lighter, custom-designed, 3D-printed replacements. Large network analyzers have been replaced with compact handheld units, and we are fabricating lightweight magnet pole pieces for transportable low-field demo magnets, etc. Fundamentals is one of our core courses and is offered at almost every session. Over 1,800 people have taken this class!

Figure 4. Fundamentals students working with cookie tins.

Figure 5. RF cavities.

In 2006, Bill Barletta became our fourth director. Leveraging his many years of service as the chairman of our governing board, a member of our curriculum committee and his considerable

Figure 6. Bill with his students.

managerial experience, he guided us through 12 years of growth and of tremendous change. Bill revived the Joint International Accelerator Schools, reinvigorated the management class series and shifted the balance of physics and engineering courses by adding more engineering courses to our curricula. He made a concentrated effort to recruit female instructors and students and established a minority outreach program. Bill established our "Iron Man" awards as a way of honoring the dedicated individuals who come back time and time again to teach for us.

Figure 7. Current USPAS team: Irina Novitski, Steve Lund, and Susan Winchester.

Steve Lund is our current director. Steve has a unique perspective: He is the first USPAS director to start out as a student, then move on to teaching for us, then join our Advisory Council and finally become director. Steve's direction for the USPAS is given in the companion article "Status and Directions of the US Particle Accelerator School."

Over the years, our funding structure has changed dramatically as has our governance. We've weathered many storms—earthquakes, hotel fires, floods, the red tide, drought, Snowmeggedon, the U.S. Office of Management and Budget's 2012 conference guidance—but one thing has always held true: We have never wavered in our commitment to education in the field of accelerator science. We have delivered more courses and issued more academic credit in accelerator science and technology than any university in the world. Over 4,700 people have attended our university-style credit courses. Many who started with us as students have become leaders in the field and have joined the faculty and governance of the school. Interest in USPAS and the impact of our programs continues to grow. We proudly quote from our 2015 HEPAP review, "USPAS technical and topical courses are essential for re-training and continued training of laboratory scientific and technical staff, and are available nowhere else. … The laboratories benefit from graduate students who enroll in USPAS. Graduate student contributions to research at the laboratories is enhanced by the training that they receive from USPAS courses in which they enroll as part of their doctoral program. Moreover, many of these students will go on to work at one of the national laboratories after graduation."

Why is the USPAS so successful? Some say it's the incredibly dedicated and talented staff—and let's face it: They're not wrong about that. But we think it's you, the accelerator community. Ranging from our students, our faculty and the national labs that contribute their employees' time to teach for us or take a course, to the universities that host our sessions and loan instructors, to the private companies that loan equipment for hands-on demonstrations in our classes, and to DOE which funds us and makes all of this possible. Thank you, and here's to another 40 years of USPAS!

IYPT 2019: UNESCO International Year of the Periodic Table

Vladimir Shiltsev *Fermi National Accelerator Laboratory*

"The Periodic Table of Chemical Elements is one of the most significant achievements in science, capturing the essence not only of chemistry, but also of physics, medicine, earth sciences and biology."

—IUPAC commemorative website, www.iypt2019.org

It has truly become a common language for science.

IUPAC continues: "1869 is considered as the year of discovery of the Periodic System, and Dmitri Mendeleev was a major discoverer. 2019 is the 150th anniversary of the Periodic Table of Chemical Elements and has therefore been proclaimed the 'International Year of the Periodic Table of Chemical Elements (IYPT2019)' by the United Nations General Assembly and UNESCO."

Accelerators played an important part in forming the periodic table as we know it now. All but two trans-uranium elements from Neptunium (93) to Oganesson (118) have been discovered at the cyclotron accelerator facilities in the U.S., U.S.S.R./Russia, Germany and Japan. In 1951, the Nobel Prize in Physics went to Glen Seaborg and Edwin McMillan for the discovery of transuranic elements, while Ernest O. Lawrence, a pioneer of modern particle accelerators, won the Nobel Prize in Physics in 1939 for his invention of the cyclotron. No surprise, the names associated with our science are widely presented in the Table – besides Og (118), these are Berkelium (Bk, 97), Einsteinium (Es, 99), Fermium (Fm, 100), Lawrencium (Lr, 103), Rutherfordium (Rf, 104), Dubnium (Db, 105), Seaborgium (Sg, 106), Bohrium (Bh, 107), Darmstadtium (Ds, 110), Flerovium (Fl, 114), Livermorium (Lv, 116), and Tennessine (Ts, 117). Mendeleev's name is commemorated, too, in Mendelevium (Md, 101). The search of heavier elements beyond 118 also requires advanced accelerators.

The periodic table exemplified the scientific approach that lead to future discoveries (like, the discoveries of Gallium, Scandium and Germanium in the two decades following Mendeleev's periodic law which originally shed light on only 63 then existing elements), and other fields of research also have similar graphical representations underlying scientific rationale behind them. For example, the table of the Standard Model of particle physics, which includes families of leptons, quarks, force carriers and the Higgs particle. Noteworthy, that modern colliders such as RHIC at BNL and LHC at CERN accelerate variety of elements – H, Xe, Al, Cu, Pb, Au, U – to the highest energies.

Fermilab and CERN celebrated the IYPT, organized colloquia, seminars and lectures on the periodic law, its history and influence.

For more information:

Know your elements? 150 years since Mendeleev's Periodic Table

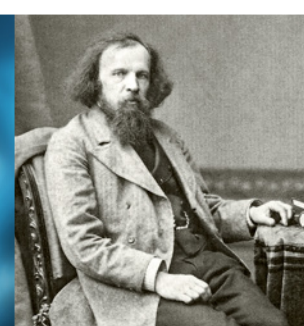
Professor M.Gordin's excellent lecture at Fermilab (video):

Discover more about IYPT2019 at https://www.iypt2019.org/.

UNESCO 2019:
International Year of the Periodic Table

www.iypt2019.org

UNESCO

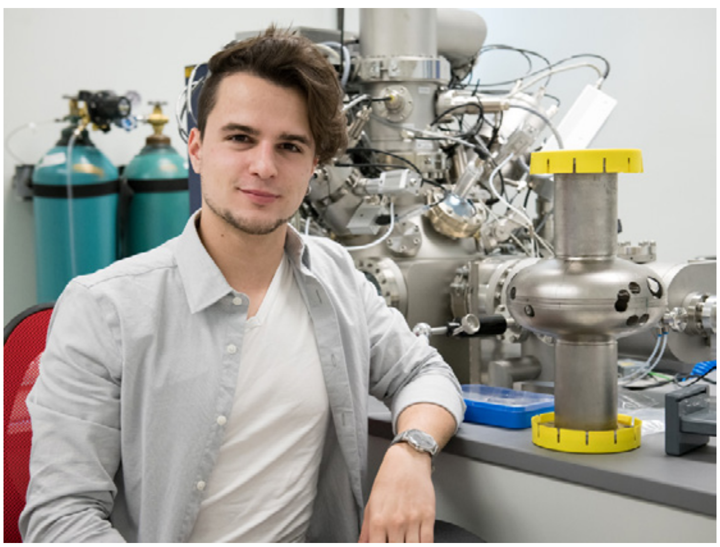


Summaries by the Student Poster Prize Winners: IPAC19

Daniel Bafia
Illinois Institute of Technology

Understanding and Pushing the Limits of Nitrogen Doping

My work focuses on understanding nitrogen doping of Superconducting Radio-Frequency (SRF) cavities and pushing this technology to achieve even higher performance. This work is motivated by the need for SRF cavities that have simultaneously extremely high efficiency (measured by the quality factor) and high accelerating fields to enable several current and future accelerators at the energy and intensity frontier. My IPAC'19 poster in Melbourne presented work on cavities subject to new optimized doping surface treatments that further increase accelerating gradients while maintaining very high quality factors.

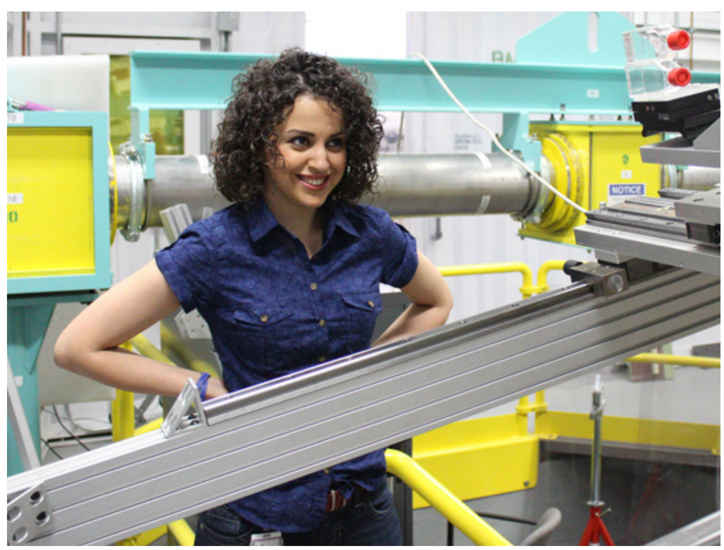


Nazanin Samadi
Canadian Light Source (CLS)
and University of Saskatchewan

Application of a Phase Space Beam Position and Size Monitor for Synchrotron Radiation

As brighter synchrotron sources are being planned and built, systems with sufficient sensitivity to monitor the electron source properties; position, angle, size, and divergence will become ever more important for diagnostic purposes and feedback to stabilize the electron beam.

We reported on a system (ps-BPM) that can measure the electron source vertical position and angle along with the vertical source size and divergence at a single location in a synchrotron bend magnet beamline. This system uses a combination of a crystal monochromator and a filter with a K-edge to which the monochromator is tuned in energy. The small range of angles from the photon source onto the monochromator crystals creates an energy range that allows part of the photon beam to be below the K-edge and the other part above. Measurement of the photon beam vertical location and width without the K-edge filter and edge vertical location and width with the filter allows measurement of the electron source position, angle, size, and divergence. Modeling and ray-tracing simulations show that the ps-BPM system has enough sensitivity to measure the electron source properties for a source with ultra-small emittance that next generation synchrotron sources will provide.



Summaries by the Student Poster Prize Winners: NAPAC19

Uttar Pudasaini
William & Mary

Recent Developments of Nb_3Sn at Jefferson Lab for SRF Accelerator Application

The desire to reduce the construction and operating costs of future SRF accelerators motivates the search for alternative, higher-performing materials. Nb_3Sn (Tc ~ 18.3 K and Hsh ~ 425 mT) is the front runner. However, tests of early Nb_3Sn-coated cavities encountered strong Q-slopes limiting the performance. Learnings from studies of coated materials related to cavity performance prompted significant changes to the coating process. The recent development of the coating process has resulted in almost Q-slope-free Nb_3Sn cavities. The best coated single-cell cavity has attained a Q_0 of ~ ≥ 2×10^{10} at 4 K and ≥ 4×10^{10} at 2 K before quenching at ≥15 MV/m. Obtaining similar results in five-cell cavities is a current goal to test them under an accelerator environment. Recently, we have produced Nb_3Sn-coated CEBAF 5-cell cavities with accelerating gradients up to 13 MV/m, which is useful for cryomodules. We plan to build a Nb_3Sn cryomodule in the near future.

Jai Kwan Bae
Cornell University

Enhanced Robustness of GaAs-Based Photocathodes Activation by Cs, Sb, and O_2

GaAs-based photocathodes are widely used to produce highly spin polarized electron beams at high currents. Spin polarized photoemission from GaAs samples requires activation to achieve Negative Electron Affinity (NEA) on the cathode surface. However, the NEA surface is extremely vacuum sensitive, and this results in rapid QE degradation. In this work, we activated GaAs samples with unconventional methods using Cs and Sb. We confirmed NEA activation on GaAs surfaces and more than an order of magnitude enhancement in charge extraction lifetime compared to the standard Cs-O_2 activation without significant loss in spin polarization.

Siqi Li
Stanford University

Measuring sub-femtosecond x-ray pulses with angular streaking

Recent sub-femtosecond x-ray pulse development at the LCLS calls for a high resolution measurement scheme to resolve the extremely short x-ray pulses. We employ angular streaking to fully characterize these sub-femtosecond x-ray pulses. Our measurements reconstruct pulse durations as short as ~300 as and peak powers approaching ~100 GW.

Julian Picard
Massachusetts Institute of Technology

The STARRE Lab: Enabling High-Power Testing of Sub-THz Accelerators

With the potential for high efficiency in a small form factor, there has been a growing interest in linear accelerator concepts driven at sub-THz and THz frequencies. Testing of these high frequency structures requires sub-THz pulses on the nanosecond timescale to avoid excessive pulsed heating. However, few sources exist that can achieve such short pulse widths at the required power level. In response to this community need we have developed the Sub-THz Accelerator Research Laboratory, or STARRE Lab, for testing breakdown rates in high gradient accelerator structures at 110 GHz. Located at the Massachusetts Institute of Technology, the STARRE Lab utilizes a laser-driven semiconductor switch to generate nanosecond pulses from a megawatt gyrotron. A laser pulse induces temporary photoconductivity in a semiconductor wafer, which then reflects high-power RF from the gyrotron towards the structure under test. By using multiple wafers and semiconductor materials, pulse widths from 3 ns to 3 us have been generated at continuously variable power levels up to 650 kW. In the course of testing of a high-frequency accelerator structure developed at SLAC, the STARRE Lab has been used to generate accelerating gradients in excess of 220 MV/m.

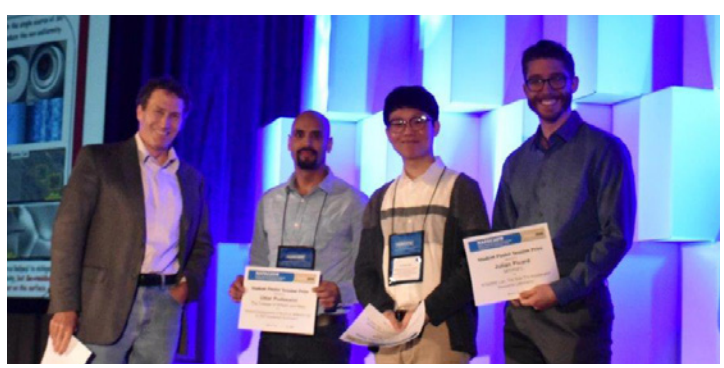
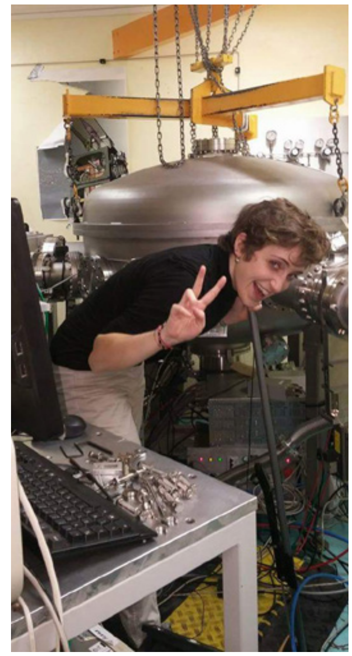


Figure 1. Scientific Program Committee Chair, T. Raubenheimer, presenting student poster prizes to three students.

2019 Outstanding Doctoral Thesis Research in Beam Physics Award Recipient

An Interview with Giada Cantono

Lund University



Let's start with your thesis research: Can you give a brief description of what it entailed and the impact it had on the field?

What a challenging question to begin with! In truth, I always felt my thesis was a part of a real "assembly chain." At the time I started my project, the ground was ready for an experimental study of plasmonics in high-field laser-solid interactions. This means we already had a preliminary picture of the effects we wanted to chase, but at the same time we knew that experiments would have launched a new, rich exchange with numerical simulations and theory in order to trace a fair and comprehensive description of our observations. I could feel a lot of expectations and enthusiasm coming from the colleagues that had worked on this topic before me, and that certainly encouraged me in pursuing accurate results since the very first weeks of my project. My supervisors were also crucial to supporting the novelty and potential of our work, knowing that it was indeed stretching out to a domain, plasmonics, that is not very common in our research area. This last point surely has consequences for how our results will impact the field, as it is obviously the community that turns a good work in longer-lasting success. About this, I am glad that since beginning my thesis, plasmonics in high-field laser-plasma interactions has been the topic of a special issue of Physics of Plasmas, which some of my collaborators during the Ph.D. project are still digging into it, and most of all that I could receive sincere interest and enthusiasm for my results from the accelerator community at the NAPAC'19 conference, where I received the APS DBP Ph.D. thesis award.

How did you get into the field of laser-plasma acceleration physics, and your research area in particular?

Unfortunately, I have no fun anecdote to present here. Physics is such a broad subject that I would be lying if I said that few other research areas were as challenging, fascinating, and could have made sense to me as laser-plasma acceleration physics. But I believe that, as in many other decisions in life, the people around me can really make the difference. So for me, coming to this domain has been mostly a lucky combination of interesting classes on optics and lasers, and the encouraging mentoring from my supervisor Andrea Macchi. Having grown a little past the naive fascination for the field that I experienced in the months after I set foot in my first plasma lab, I still think that our research area offers a balance between studies of fundamental physics and aspirations of within-reach applications. And being an experimentalist allows me to brag about the laser power we use on a daily basis!

What was the greatest challenge you faced during your Ph.D. (technical or otherwise)?

My Ph.D. supervisor in France, in the face of the technical struggles and adversities, used to repeat: "You know, in ten years time you will remember this and laugh so much about it." It is not something that a picky, ambitious student would like to hear while mopping the floor of the flooded lab and estimating the amount of lost laser time, but three years later I can say that there was some truth in it. So many of the problems that we solved (or not) somehow seem minor today. Yet, my greatest personal challenge can be reduced to not feeling up to the task, being afraid that the quality of the results (or lack of it) was diminishing the efforts and commitment that I have always devoted to my work. Losing a bit of the perspective on the project and therefore the motivation in it. The hardest, and probably most educating experience of the Ph.D. as a whole was then to find a meaning in the long days spent in the lab, or munching data, to give the efforts of getting the results the same dignity as the good results themselves.

What advice do you have for current graduate students in laser-plasma acceleration physics?

I would advise them not to be afraid to present their work in as many occasions as possible: conferences, summer schools, poster sessions, internal seminars, etc. Even if the results might seem preliminary, coarse, or of little importance, fresh eyes can always give new angles and perspectives. In my short career I met scientists looking for the breathtaking plot that would dismiss my huge error bars with an embarrassed smile, but also encouraging researchers that with priceless modesty looked at my results and with their questions, impressions and suggestions allowed me to place my work in a wider context, I would say even to value it beyond the four walls of the lab and the somehow repetitive interactions with my own self-doubts and the supervisors' feedbacks. So, do not be shy. Interacting with experienced researchers is an optimal way to be reminded that each step in your own education, however small or wobbly, is contributing to your professional and personal growth.

What are you doing now? Is it a continuation of your previous research, or are you starting something new?

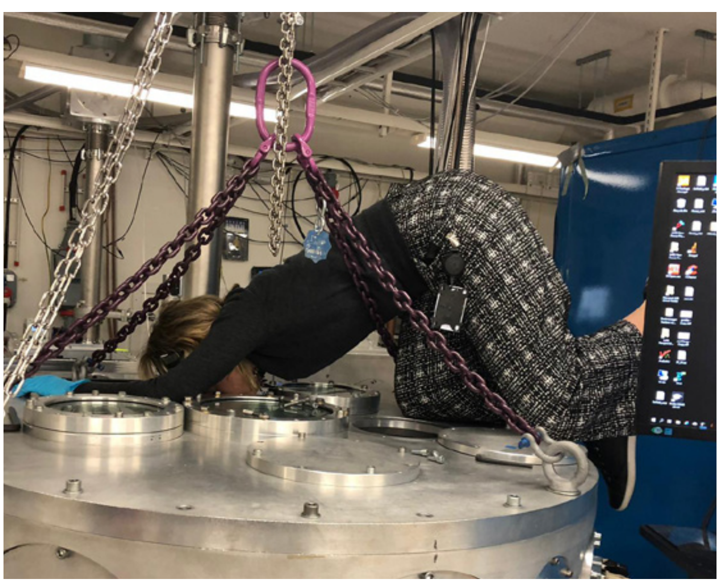
After the Ph.D. I accepted a postdoctoral position in the department of physics at Lund University in Sweden. I still work on laser-solid interactions with a powerful laser, but I have broadened the topic of my research from plasmonics with structured targets to more general studies on laser-driven proton acceleration. In many ways, this position has granted me a larger freedom to plan for different experiments, but a new environment always requires a period of adaptation, both to the facility and to the new colleagues. Up to now, this has resulted in a marvelous collection of experimental attempts with not-so-groundbreaking results, yet with a great improvement of the setup. I have the feeling that exciting experiments will be on their way soon. Didn't I just mention something about an assembly chain?

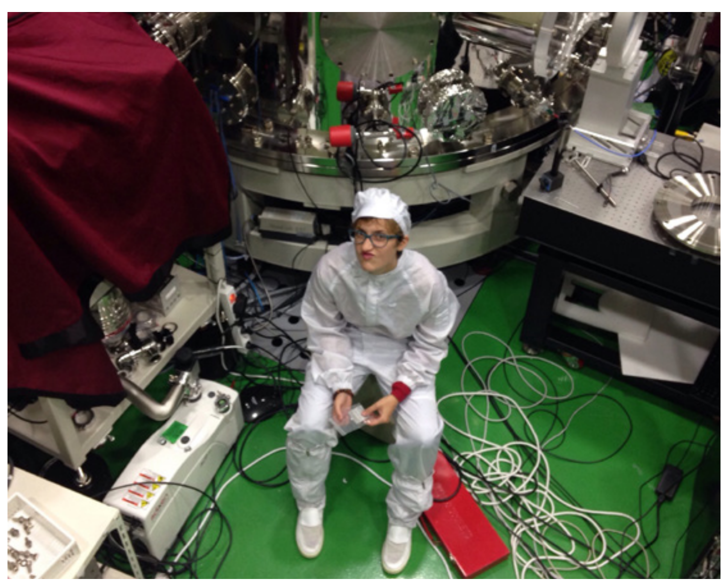
Any plans /aspirations for the future?

I am still figuring everything out. I enjoy the freedom granted by research, although sometimes I dread its lack of structure or organization. Whenever I consider quitting research, I also remember how dynamic and diversified and filled with opportunities and enthusiasm this environment can be. So yes, maybe I would like to stick around for a while more. I also have a side dream that involves working with science communication, and the more I receive positive feedback about it, the more I find myself believing in it. I am so pleased that the accelerator community enjoyed the presentation of my Ph.D. thesis at NAPAC'19!

Tell us a fun fact about you! An interesting hobby, perhaps.

I actually asked my mother and, on the other side of the spectrum, a Swedish colleague for help with this question. That is because I could talk for hours about my weekend DIY projects and not focusing on any one in particular. My mom suggests that I talk about the amigurumi. They are small, stuffed toys realized with crochet, coming from the Japanese culture. I started making them at my university, after learning the basics of knitting and crocheting and not daring to challenge my mother in the creations of sweaters and cardigans and t-shirts and hats and socks and—anything more? Oh yes, scarves, I made a couple scarves. Now I have basically saturated my family and friends with cute childish animals. My friend and colleague Kristoffer (who just won an amigurumi for helping me with this) declares that I "name things." It's true that I may have named my laptop Richard, my vacuum-cleaner Lucas and my whimsical orchid Amanda, but I promise there is a philosophy behind it. I will just keep the suspense until next time.





Upcoming Events

Date	Title	Location
Conferences & Meetings		
2020		
March 2–6, 2020	APS March Meeting 2020	Denver, Colorado (US)
April 18–21, 2020	APS April Meeting 2020	Washington, DC (US)
May 10–15, 2020	International Particle Accelerator Conference (IPAC’20)	Caen, France
July 13–17, 2020	11th International Conference on Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI’20)	Chicago, Illinois (US)
August 30–September 4, 2020	Linear Accelerator Conference (LINAC’20)	Liverpool, United Kingdom
September 13–17, 2020	International Beam Instrumentation Conference (IBIC’20)	Sao Paulo, Brazil
September 14–16, 2020	ICFA Advanced Beam Dynamics Workshop on High Luminosity Circular e+e- Colliders (eeFACT’20)	Elba, Italy
October 5–9, 2020	ICFA Advanced Beam Dynamics Workshop on High-Intensity and High-Brightness Hadron Beams (HB’20)	Batavia, Illinois (US)
2021		
March 15–19, 2021	APS March Meeting 2021	Nashville, Tennessee (US)
April 17–20, 2021	APS April Meeting 2021	Sacramento, California (US)
May 23–28, 2021	International Particle Accelerator Conference (IPAC’21)	Foz do Iguazu, Brazil
June 30–July 5, 2021	International Conference on RF Superconductivity (SRF’21)	Grand Rapids, Michigan (US)
August 23–27, 2021	International Free-Electron Laser Conference (FEL’21)	Trieste, Italy
October 16–22, 2021	International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS’21)	Shanghai, China
Accelerator Schools		
January 13–24, 2020	U.S. Particle Accelerator School (USPAS) Winter 2020	San Diego (CA), United States
June 15–26, 2020	U.S. Particle Accelerator School (USPAS) Summer 2020	Melville (NY), United States
January 13–19, 2020	Joint Universities Accelerator School (JUAS)	Archamps, France
March 22–April 4, 2020	CERN Accelerator School: RF for Accelerators	Kaunas, Lithuania
May 25–June 7, 2020	CERN Accelerator School: Mechanical Materials Engineering for Particle Accelerators and Detectors	Sint-Michielsgestel, Holland

In Memoriam

Christina Swinson-Cruz & Wilfried Wurth

Wednesday, Dec. 12, 2018

Christina Swinson-Cruz, accelerator physicist and Deputy Director of Brookhaven Lab's Accelerator Test Facility, dies at age 39

By William Safer

Originally published on the Brookhaven National Laboratory website in July 2019: www.bnl.gov/newsroom/news.php?a=216675

Swinson-Cruz joined the Lab Sept. 2, 2010, as a research associate in the Physics Department working on the ATF. She moved with the rest of the ATF team to the Collider-Accelerator Department in April 2013 where she was named assistant scientist in 2014, and associate scientist in 2016. In October 2017, she was named Deputy Director of the ATF, supporting facility Director Mark Palmer.

Throughout these years, Swinson-Cruz made major contributions to the operation of the facility both as an electron beam operator and researcher, and by supporting the facility's transition to a U.S. Department of Energy (DOE) Office of Science National User Facility in 2015. Since then, she played a central role in interfacing with the broader advanced accelerator and laser science community to define the critical science priorities for the ATF's future.

"Whatever she got involved in she invested herself completely," Palmer said. "She was committed to operational excellence of the facility while simultaneously pursuing opportunities to expand her own research efforts." This culminated in November 2018 when the ATF's Program Advisory Committee gave a new experiment that she designed and proposed its highest scientific rating – an experiment that the rest of the ATF team will now be executing to her high standards.

Swinson-Cruz was born in Darwen and grew up in Rishton in Lancashire, England. She studied physics with computing at Queen Mary College at the University of London, earning her bachelors in science in 2005, and did her doctoral work in accelerator physics at the University of Oxford under the guidance of Prof. Phil Burrows. As part of her doctoral work, she conducted studies from 2005 to 2008 at the Stanford Linear Accelerator Center (SLAC) and from 2007 to 2009 at the High Energy Accelerator Research Organization known as KEK in Tsukuba, Japan.

Accelerators

In 2017, for the Lab's effort to develop an electron-ion collider, Swinson-Cruz worked closely with Brookhaven physicist Steven Brooks on successful tests at the ATF of a special guide channel to transport electron beams over a wide range of energies. She steered the first beam through the ATF line and played an essential role in running the experiments.

In the second half of 2018, Swinson-Cruz helped Palmer and others at the Lab to organize an accelerator outreach event, "Accelerating to a Bright Future," to showcase the capabilities of Brookhaven's accelerators to potential partners. The event allowed the Lab to develop new connections that are expected to yield future accelerator partnerships and helped to cement several efforts that were in their formative stages.

Mentor/Mentee

Swinson-Cruz participated in Brookhaven's Mentoring Program, and was a mentee to Lab Director Doon Gibbs.

"I was aware that she was a very talented physicist early on after she got here," Gibbs said. "She was young, energetic, and motivated—really interested in what she was doing, both at ATF and in her career. But what I learned as her mentor was, in addition to being a talented physicist, she was also a science leader."

Swinson-Cruz had a knack for seeing the big picture, Gibbs said.

"She could talk about her strengths and weaknesses and those of others in a way that was balanced, forgiving, and appropriate," he recalled. "And she was focused on the end game, with what we could accomplish by working together and how we could get there."

Gibbs said that focus helped her as a representative of Brookhaven Women in Science (BWIS), the nonprofit organization based at the Lab that promotes opportunity for women in science.

"At our first meeting after she took on a leadership role in BWIS, I agreed with her that there was work to be done to improve our performance in I&D. She was open in acknowledging the facts and then we moved on to what we were going to do about them," he said. "She listened to plans, and commented constructively about what she thought was good and what could be improved. She was a very effective partner in that regard and as a result had a significant impact. She was a natural leader."

Bringing Women and Other Underrepresented Groups to Science

Swinson-Cruz was an advocate for bringing women and young people from different backgrounds into science, and into physics in particular. She was active in Brookhaven's Association for Students and Post Docs, serving as the organization's president in 2014. She also mentored students from local high-schools.

Her friend and fellow BWIS member Kathy Walker recalled conversations to persuade Swinson-Cruz to join to take on a leadership role in BWIS.

“I wanted to bring younger people in, people who were interested in the issues and could do something about it,” Walker said. “And I saw she had a lot to offer, how she was a good person, a nice person.”

In 2013, she was featured in a U.S. Department of Energy (DOE) web series “Women @ Energy,” that highlighted women improving the world through their careers in science, technology, engineering and mathematics (STEM) across the DOE complex.

And at a 2013 Women’s History Month event, Swinson-Cruz spoke of her decision to pursue physics—and shared the advice she received from school advisors and her parents at critical moments along her academic and career journey.

Wednesday, May 8, 2019

On May 8, 2019, Professor Wilfried Wurth dies at the age of 62.

By Jochen Schneider

Originally published on DESY inForm Nr. 2|19.

On May 8, 2019, Prof. Wilfried Wurth died unexpectedly at the age of 62 during a business trip to Sweden. This was a shock for his family and to many colleagues and friends all around the world, especially at DESY and at the Universität Hamburg. Wilfried Wurth studied physics at the Technical University of Munich. For his diploma thesis and PhD he joined Prof. Dietrich Menzel’s Institute for Chemical Physics of Surfaces at the TUM. After two years of post-doctoral research at the IBM Almaden Research Center in San Jose, USA, he returned to TUM, did his habilitation and worked as a senior researcher and lecturer. Wilfried Wurth did experiments at synchrotron radiation sources in Germany, Italy, the US and Japan, but also calculations mainly with the x-alpha method during and after his stay at Almaden. He has done pioneering work exploring the use of the Auger Resonant Raman Effect for unravelling ultrafast electron transfer dynamics in layers of atoms and molecules on surfaces. During the last years of his Munich time he designed and constructed a source for size-selected clusters and extended his X-ray based investigations to nano objects, a branch of science that he continued after his move to Hamburg.

Attracted by the free-electron lasers (FEL) under construction or in an advanced planning stage at DESY, respectively, Wilfried Wurth accepted the offer to become full professor for experimental physics at the Universität Hamburg in the year 2000. He moved into offices and laboratories on the DESY campus and collaborated intensively with the Hamburger Synchrotronstrahlungslabor HASYLAB.

From the beginning, Wilfried Wurth was heavily engaged in realising the world’s first VUV/soft X-ray FEL named FLASH starting user operation in 2005, and in building beamlines and novel instruments for the best possible science with this revolutionary facility. He has been one of the most prominent researchers at FLASH and was also spokesperson of the BMBF priority programme FLASH. This first priority programme in the field of condensed matter was created to bundle research at the free-electron laser within the framework of collaborative project funding, which allowed university groups to actively participate in the development of novel instrumentation. His contributions to advisory bodies such as the ELETTRA SAC and various review panels on synchrotron and FEL radiation sources were highly appreciated. He also chaired for many years the Komitee für Forschung mit Synchrotronstrahlung (KFS) in Germany.

Wilfried Wurth’s own research focused on the investigation of ultrafast processes, such as real-time observations of chemical reactions at surfaces and the dynamics of electrons in solids and at interfaces. For example, his group succeeded in conducting breakthrough experiments on dynamic processes in condensed matter. Much of his scientific legacy is reflected in his review paper entitled “10 years of pioneering X-ray science at the Free-Electron Laser FLASH at DESY”, which became online available shortly before he passed away.

Wilfried Wurth was very instrumental in setting up the Center for Free-Electron Laser Science CFEL, a joint enterprise of DESY, the Max-Planck Society and the Universität Hamburg with the goal to develop novel approaches for the investigation of structure and dynamics of matter. Since 2007 Wilfried Wurth led the Advanced Study Group of the University at CFEL, which bundled the activities of the various university groups involved. He was one of the leaders of the international consortium for rapid realisation of the Soft X-ray Material beamline (SXR) at LCLS, which was essential for the early scientific success of LCLS. All together, these CFEL activities facilitated German and European scientists to be successful in the peer review proposal selection process and to gain hands-on experience with X-ray FELs early on, which is very important for early success of the European XFEL.

In 2014 Wilfried Wurth was appointed Lead Scientist at DESY for taking the scientific lead at FLASH at by keeping his commitments of a Professor at the Universität Hamburg. In this new position he particularly aimed to maintain the status of FLASH as pioneering X-ray light source and to make sure that FLASH will continue to be one of the world’s leading facilities for research at free-electron lasers.

Throughout all his professional life Wilfried Wurth regarded strong links to the University, teaching students and guiding PhD students and post-doctoral fellows as most important and highly motivating.

We will very much miss him at DESY. He was a great, visionary scientist and academic teacher, and a wonderful personality. Leading by example, he had enormous impact on photon science research and technical developments at DESY, on the education of students at the physics department, and on the synchrotron radiation community at large.

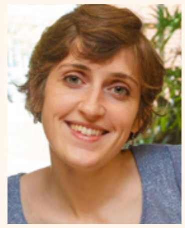
APS DPB Awards & Fellowships

Robert R. Wilson Prize for Achievement in the Physics of Particle Accelerators, 2019

Bruce Carlsten, Los Alamos National Laboratory

Citation: "For the discovery and subsequent implementation of emittance compensation in photoinjectors that has enabled the development of high brightness, X-ray free electron lasers such as the Linac Coherent Light Source."

Outstanding Doctoral Thesis Research in Beam Physics Award, 2019



Giada Cantono, Lund University

Citation: "For pioneering work on surface-plasmon enhanced radiation sources in ultrashort laser-grating interaction at relativistically strong intensities, which led to the demonstration of a source of beamed, quasi-collinear high charge multi-MeV electron bunches and attosecond XUV photon bursts."

APS Fellow Nominations by the DPB in 2019

Matthias Ulf Liepe, Cornell University
Citation: "For multiple contributions to the fundamental science and engineering of radiofrequency superconducting materials, accelerating cavities, cryomodules, and instrumentation and controls, and for excellence in graduate and undergraduate physics education."

Ji Qiang, Lawrence Berkeley National Laboratory
Citation: "For extensive contributions and leadership in theoretical and computational beam and accelerator physics, and for pioneering application of high-performance computing in the field."

Alexander Romanenko, Fermi National Accelerator Laboratory
Citation: "For groundbreaking contributions to understanding radio frequency power losses in superconducting radio frequency cavities for particle accelerators."

Frank Schmidt, CERN
Citation: "For groundbreaking work in furthering the understanding of nonlinear particle motion in accelerators through experiments and simulations."

Nikolay Vinokurov, Budker Institute of Nuclear Physics
Citation: "For pioneering theoretical and experimental work in the field of free electron lasers and undulators for synchrotron radiation sources and free electron lasers."

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(301) 209-3200
(301) 209-0865 FAX

Editorial Office
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: Troy Rummler
Layout Editor: Tyler Small (The Field's Five)