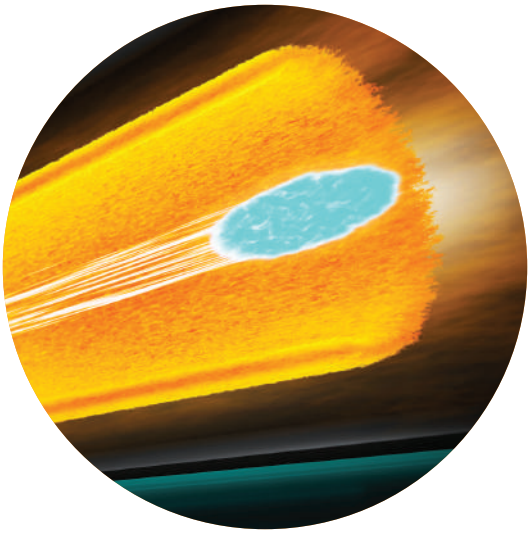


Image: Conceptual image of positrons being accelerated inside a hollow tube of electrons. See page 28 for details.
Photo Credit: Greg Stewart

APS DPB NEWS

APS Division of Physics of Beams Annual Newsletter ////////// **2017**

In this Issue:

Dear Readers,

In the past year, it has been inspiring to see how the accelerator community exemplifies scientific research as a unifying force. Our field, by virtue of the complexity of accelerator design and engineering and the broad range of accelerator applications, brings together a remarkably diverse group of individuals. This year's newsletter highlights research in fields as far apart as art and antiquities, machine learning, and dark matter. In addition to fruitful interdisciplinary collaborations, articles on SESAME (a new light source in the Middle East), MAX IV, Fermilab's 50th anniversary and the European XFEL demonstrate the opportunities afforded by accelerators to bring scientists together from various nations and sociopolitical backgrounds, developing stronger ties and mutual respect between them.

In addition to these inspiring feature articles, we've added some new recurring sections to the newsletter for our early career members, including an interview with the DPB Dissertation Award Recipient and a section highlighting a university lab. This year, we hear from Professors Rosenzweig and Musumeci on high impact research underway at UCLA, from beam manipulation using THz radiation to inverse free electron lasers. Next year… is up to the reader! Please let us know if you would like your university lab featured.

Finally, we'd like to share a new development in the editorial process. As of this year, editing the DPB newsletter will be a little less lonely. In an effort to smooth the transition from one year to the next, the editorial team will consist of both early-career members-at-large. Each year, as one of the two early-career members rotates off and is replaced, there will be continuity from the other member who served as co-editor in the previous year. This new succession plan should enable us to provide you a high-quality newsletter year after year.

Enjoy,

Alysson Vrielink
APS DPB Newsletter Co-Editor
and Early Career Member-at-Large
PhD Student, Stanford University
vrielink@stanford.edu

Sam Posen
APS DPB Newsletter Co-Editor
Associate Scientist,
Fermi National Accelerator Laboratory
sposen@fnal.gov

From the Chair

Tor Raubenheimer
SLAC National Accelerator Laboratory

As the DPB Executive Committee Chair for 2017, it is my pleasure to provide you with a brief report of our activities this past year. But first, I want to thank Alysson Vrielink and Sam Posen for their hard work in getting out the third consecutive newsletter!

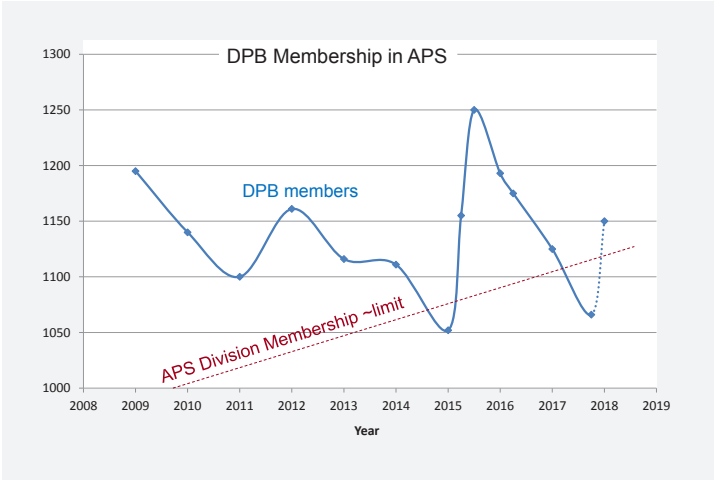
This year has been a very exciting year, with many new, large-scale accelerator facilities coming online including the Swiss-FEL at the Paul Scherrer Institut, the Pohang XFEL at Pohang Accelerator Laboratory, the SX-FEL at the Shanghai Institute of Applied Physics, and the EuXFEL at the Deutsches Elektronen-Synchrotron. The EuXFEL is the largest demonstration of SRF technology generating >15 GeV beams in 1 ms pulses. The High-Luminosity LHC project and the ESRF Upgrade projects are making great progress. In the U.S., Thomas Jefferson National Accelerator Facility's 12 GeV Upgrade formally completed construction with the approval of CD-4 and the LCLS-II construction is making great progress with installation of the SRF linac to begin in mid-2018. The APS-Upgrade has begun long-lead purchases, the LHC High-Luminosity Accelerator Upgrade Project completed its CD-1 review in the summer, and Fermi National Accelerator Laboratory's PIP-II upgrade is planning a CD-1 review in December.

The DPB has been working hard this year to accomplish our many objectives: promoting research in the science of beams, publication in scholarly journals, enhancing education in beam science and technology, providing a forum for communication via sponsorship of conferences and, of course, this newsletter. This year, the DPB Publications and the Education, Outreach, and Diversity Committees have taken stronger roles. The Publications Committee, chaired by Alex Bogacz, ran a survey to review the state of journals for accelerator science and technology and is developing guidelines for peer-review of some papers submitted to IPAC'18. The Education, Outreach, and Diversity Committee, chaired by Swapan Chattopadhyay, is focused on improving the pipeline of graduate students in accelerator science and technology and will release a plan early next year.

During the year, we organized and sponsored sessions at the April APS meeting (held in January) in Washington, D.C., and the March APS meeting in New Orleans. We believe that the April and March APS meetings are a great opportunity for outreach, and we would appreciate your input on how we can enhance DPB's role in these meetings. Planning for IPAC'18, the next Particle Accelerator Conference to be held in Vancouver, British Columbia, is well underway (https://ipac18.org). The invited program has been posted on the website, and abstracts are due by December 2, 2017. An exciting addition to the program this year is a set of student tutorials on April 28th and 29th. Undergraduate and graduate students as well as postdocs are encouraged to attend: details can be found at https://student-tutorials.ipac18.org/.

Our community is facing new challenges in the coming years, among them is the reduction in research funding. The current budgets in the U.S. are challenging. Informing members of Congress of the role and relevance of physics research, and specifically accelerator physics and technology, can help. The APS Office of Public Affairs can be helpful in supporting visits to Congress and providing guidance for creating a constructive dialog.

Another challenge is that for the last several years DPB membership has been in a precarious position, hovering just above the threshold required to maintain Division status. It is critical for our Division to continue efforts toward increasing membership in order to continue serving our community. I encourage each member of DPB to make the case for membership and to encourage your colleagues, including accelerator physicists and accelerator users, to join. We welcome your suggestions on how DPB can be more effective in dealing with this issue.



DPB Membership as a function of time compared to the increasing requirements to maintain APS Division status.

From the Secretary Treasurer

Stan Schriber
Professor Emeritus, Michigan State University

Overall, the DPB is performing very well as an APS Division. We are interacting well with other professional societies and government organizations involved in accelerator-related activities. Financially, the DPB is doing well, but we need to address the fact that while the overall APS membership numbers are increasing significantly each year, the DPB membership numbers remain constant. DPB membership is now a serious concern because of its impact as to whether the DPB will remain an APS Division in three years. After much detailed discussion on DPB membership statistics, the executive committee unanimously decided that the DPB should increase the number of Early Career Members-at-Large on the Executive Committee (EC) from one to two.

Over the past year, the DPB has provided funds to support the worldwide shipping costs of the Accelerator and Beams brochure, the annual newsletter, the APS International Research Travel Award Program, a student support program that funded students to attend NAPAC16 and IPAC'17, the WISE event, and the short courses and Teacher's Day at NAPAC16. They covered costs of meetings held at the APS 2017 April meeting and at NAPAC16, as well as a breakfast interaction for students and DPB members attending the latter. The DPB income is generally spent on these kinds of activities.

Rather than only have two EC meetings per year, the EC decided to hold several teleconferencing meetings during the year using GoToMeeting. We are not only maintaining updates to our DPB website page and using an "Action Tracker" list to keep record of actions outstanding and completed, but we are also setting up a system for maintaining all of our past and active records on a protected site with usernames and passwords for various components of the records system.

A new Memorandum of Understanding for management and operation of xPAC conferences in the Americas between APS-DPB, IEEE-NPSS-PAST, PAC OC and IEEE-NPSS was approved by the four organizations in November 2016.

Details and registration at https://student-tutorials.ipac18.org/

2016 North American Particle Accelerator Conference (NAPAC16)

Marion White
Argonne National Laboratory

The 2016 North American Particle Accelerator Conference, NAPAC16, was held October 9-14, 2016, at the Sheraton Grand Chicago Hotel in the heart of downtown Chicago. The conference was co-sponsored by the American Physical Society (APS) and IEEE, and hosted by two Chicagoland national laboratories – Argonne and Fermilab. Dr. Marion White (Argonne National Laboratory) served as conference chair, and Dr. Vladimir Shiltsev (Fermi National Accelerator Laboratory) served as program chair. Ms. Maria Power served as conference proceedings editor and scientific secretary.

More than 500 experts attended NAPAC16 representing all areas of accelerator science and technology. It is the largest domestic particle accelerator conference and covers the whole spectrum of accelerator science, engineering, and technology topics. As such, NAPAC16 was particularly valuable for students, postdocs, technicians, and engineers, who were exposed to the entire field in one place. Delegates presented more than 130 invited and contributed talks and 370 posters. Presenters received feedback on their research including many helpful suggestions and solutions to problems.

Six IEEE-sponsored short courses on highly-relevant accelerator topics were offered on Sunday morning before the conference, overlapping with the Chicago Marathon; registered students received academic credit for the courses. The excellent Short-Course program was organized by Dr. Bruce Carlsten (Los Alamos National Laboratory). Students and early-career scientists and engineers made up more than one quarter of the conference attendees. The student program was organized by Dr. Katherine Harkay (Argonne). A special student poster session took place during the welcome reception on Sunday. Sixty students participated, of which 12 received Student Poster Awards. Students were also encouraged to present their posters in the regular sessions for additional exposure.

The conference began with overview talks reflecting the needs and plans for accelerators for high-energy physics research (Prof. Young-Kee Kim, University of Chicago), basic energy sciences (Dr. Michael Dunn, SLAC National Accelerator Laboratory) and nuclear physics (Dr. Rolf Ent, Thomas Jefferson National Accelerator Facility). Dr. Vito Mocella (Institute for Microelectronics and Microsystems, Italy) presented the closing talk on how synchrotron radiation facilities are helping to reveal long-buried secrets contained in burnt papyri scrolls from the ancient Roman town of Herculaneum, destroyed by volcanic pyroclastic flows in 79 AD.

From the Awards Session: (left to right) Maury Tigner, Marion White, William Foster, Vasily Parkhomchuk, Vladimir Shiltsev, Ilan Ben-Zvi

The 2016 Louis Costrell Awards Session began with a talk by Representative Dr. William Foster, the only physicist in Congress, who discussed "What Life is Like as a Scientist in Congress" and encouraged scientists and engineers to consider politics as a career.

The Women in Science and Engineering (WISE) event was organized by Ph.D. students Auralee Edelen and Nihan Sipahi (Colorado State University) and received excellent commendations from all who attended. The Teacher's Day event, organized by Prof. Linda Spentzouris (Illinois Institute of Technology) attracted high school physics teachers from around the Chicago area. They listened to talks and performed experiments using kits provided to them, which they then took home to share with their students. Laboratory tours of Argonne and Fermilab accelerators were held the Saturday following the conference.

Attendees developed new contacts within the U.S. and internationally, and strengthened existing collaborations. More than thirty of the most prominent accelerator vendors sponsored booths and helped support NAPAC16. It was an excellent venue for all conference attendees to bring themselves up to date on the newest developments in accelerator technology. Two national laboratories purchased booths to inform participants of current and future projects and job openings, and there was an active job-postings board. Conference proceedings are available at www.jacow.org.

The Eighth International Particle Accelerator Conference (IPAC 2017)

Gianluigi Arduini and Mike Seidel
CERN and the Paul Scherrer Institute

This year, the Eighth International Particle Accelerator Conference took place in Copenhagen, Denmark—the world's happiest country according to the U.N. World Happiness Report 2016—May 14-19, and it was visited by more than 1,550 people from 34 different countries. Hosted by the European Spallation Source (ESS), it was supported by MAX IV and Aarhus University. It was organized under the auspices of the European Physical Society Accelerator Group (EPS-AG) and the International Union of Pure and Applied Physics (IUPAP).

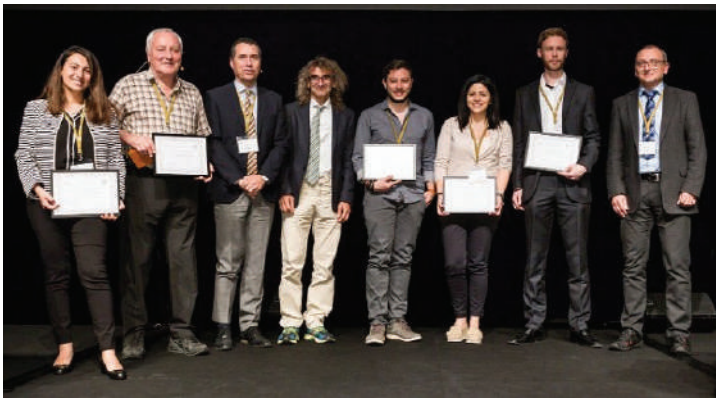
The IPAC'17 scientific program opened with a presentation on the successful commissioning of one of the most brilliant sources of ultra-short flashes of X-rays, the European XFEL at DESY. First lasing was achieved a few days beforehand, just in time for the announcement at the conference.

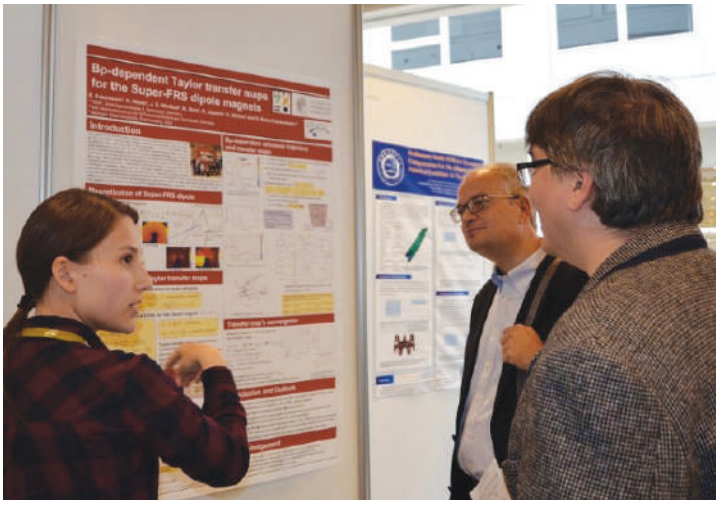
An industrial exhibition took place during the first three days of the conference and during the welcome reception on Sunday evening. A record number of industrial exhibitors came (115 companies from 16 countries) and presented their high technology products and services to the delegates. The industrial exhibition was complemented by an enlightening session on engagement with industry—featuring IPAC's first panel discussions on industry as a career path for physicists—and open source vs closed source intellectual property in the domain of particle accelerators and their applications.

The entertaining talk "Illuminating Anti-matter: The ALPHA Antihydrogen Experiment at CERN" was certainly a highlight of the conference. Since trapping anti-hydrogen has become possible in CERN experiments, the fundamental (and intriguing) question of whether matter and antimatter obey the same laws of physics is being addressed. The talk—a well-balanced combination of technical aspects and light, high-spirited intermezzos—described the steps that led to the successful trapping of antimatter. Together with the equally exciting talk "From Niels Bohr to Quantum Computing" in the closing session this gave a wide perspective on some of the present physics challenges and applications, while two other closing talks gave an overview and perspective of two domains for which accelerators were initially conceived: nuclear and particle physics.

In total, there were 45 invited and 51 contributed oral presentations and approximately 1,400 posters were scheduled during lively, dedicated sessions at the end of each afternoon. A special student poster session took place during registration the day before the conference opened. The proceedings of IPAC'17 are published on the JACoW site. Thanks to the work of the dynamic JACoW team and the careful preparations and guidance of Chief Editor Volker Schaa (GSI), a pre-press version was published on the last conference day. The final version was available just three weeks after the conference. This is yet another impressive record set by the JACoW International Collaboration.

The ninth IPAC will take place in Vancouver, Canada on April 29 - May 4, 2018, including student tutorials on April 28th - 29th, 2018.





Top: The IPAC17 EPS-AG Prizes Award ceremony. From left: Anna Grassellino, Lyndon Evans, Oliver Brunning, Pantaleo Raimondi, Fabrizio Guiseppe Bisesto, Annalisa Romano, Daniel Hall, Mike Seidel /// **Bottom:** Discussions during the student poster session

SESAME: A Personal Point of View

Eliezer Rabinovici
Racah Institute of Physics, Hebrew University of Jersusalem

On May 16, 2017, under the roof of a gigantic tent in Allan, Jordan, a journey that started on November 19, 1995, under another crowded Bedouin tent in the Sinai reached an important milestone. Official delegates from Cyprus, Egypt, Iran, Israel, Jordan, Pakistan and Turkey not only remained in their seats to listen to each other but also shared speeches with a common message: the importance of appreciating and encouraging science as a bridge for understanding.

The occasion for this unique event was the opening of a new third-generation regional light source in Jordan, the Synchrotron-light for Experimental Science and Applications in the Middle East. SESAME is the Middle East's first major international research center and includes members Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority, and Turkey. It is expected to start working scientifically in earnest this year.

The story of SESAME is a story of many dedicated people from all over the region and the globe. Some have been very visible, while others contributed far from the limelight out of belief in the project. For me, it is the fulfillment of a dream—a dream that Arabs and Israelis can work together for the benefit of humanity as well as for their own people, with each bringing their scars to the collaboration as well their goodwill.

SESAME and Science as a Bridge for Understanding

Anyone embarking on such a prospect needs an infinite, and nothing less than infinite, sense of optimism.

Why Science? Science is a common language. When scientists meet, they need not spend large amounts of time just to agree on the basic terms for communication. This crucial simplification allows them to work side by side. Additionally, the professional appreciation that develops from their collaboration has the potential to lead to a deeper personal connection and mutual trust.

Why Scientists? Scientists of all nations not only have a common language, many of them have a track record of participating in successful international collaborations such as at CERN and Fermilab. With the privilege to pursue pure and applied knowledge, scientists have a duty to contribute back to society. One such way is to build a bridge of understanding between nations.

What kinds of projects should one use as bridges? The first prerequisite for a successful collaboration is that each side has something essential to contribute and to gain from the project. My own tendency is to encourage grassroots initiatives in scientific research and to strengthen intimate collaborations. However, I had to accept that the most viable approach in the case of SESAME was to focus on a large scale, top-down approach. One can compromise on the approach, but one must not compromise on the quality of the project. Only first class science can serve a useful purpose in "Science for Understanding" attempts. It is better not to have a project at all than to have a mediocre one! This theme follows SESAME throughout its history.

From the CERN Corridors through Sinai Beaches to the SESAME Concept

My involvement in SESAME started after the Oslo Accords when Italian Professor Sergio Fubini from CERN approached me in the corridor of the Theory Group at CERN to inform me that it might be time to test what he called my "idealism." He was referring to my ideas on future, joint Arab-Israeli scientific projects. Together with many others from the region and the world we founded the Middle Eastern Science Committee (MESC) to try to forge meaningful scientific contacts in the region. CERN was an especially appropriate venue for the inception of such a project. CERN itself was built after World War II in an effort to help heal Europe by uniting European scientists and promoting understanding through science.

To focus our vision, Sergio gave me some homework. He invited me to deliver two talks at a meeting in Torino, Italy, to be held on his 65th birthday. One talk was a mini review on the status of string theory (my field of research), and the other was on the status of Arab-Israeli collaborations. Following the meeting in Torino, we traveled to Cairo to meet Professor Venice Gouda, the Egyptian Minister of Higher Education, and other Egyptian officials. As a result of that meeting, we collaborated with the Egyptian authorities to organize a high-quality scientific meeting in Dahab in a large Bedouin tent in the Sinai desert. The meeting was held November 19-26, 1995, bringing together about one hundred young and senior scientists—Egyptian, Israeli, Jordanian, Palestinian, and Moroccan scientists and other outstanding researchers from around the world. This included present and

future Nobel and Fields Medal laureates. Gouda opened the meeting by announcing a moment of silence to honor the murdered prime minister of Israel, Yitzhak Rabin,. Among other good omens, the meeting passed safely through a considerable earthquake that shook Mount Sinai.

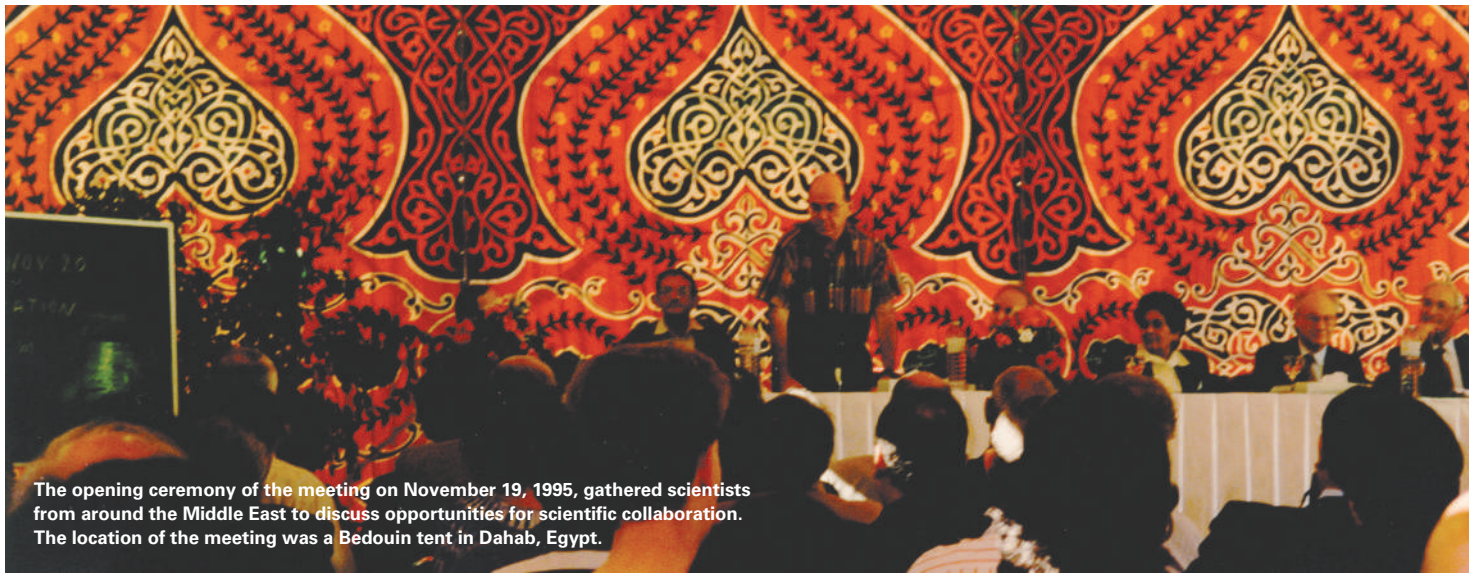
A worsening political situation blocked attempts to continue the project in the region itself, and MESC decided to retreat to Torino. During a meeting in November 1996, one section studied the possibilities of cooperation via experimental activities in high-energy physics and light source science. During that session, the late German scientist Gus Voss suggested, on behalf of himself and Hermann Winnick from SLAC, bringing the soon-to-be dismantled BESSY, a German light source situated in Berlin, to the Middle East. Herwig Schopper, a former Director-General of CERN, attended this workshop and gradually replaced Fubini, who transitioned his leadership role to others. The operation of MESC up to this point produced sufficient trust among the parties as well as the infrastructure to transform this idea into something concrete.

From a Name to a Real Structure

Schopper narrowed down the many options for collaboration to constructing a light source, which was very attractive thanks to the rich diversity of scientific fields that benefit from light sources. Such diversity would allow the formation of a critical mass of users in the region. In fact, one virtue of the decades it took to build SESAME is that it provided time to build up a significant community of potential users. The International Atomic Energy Agency in Vienna was a key financial supporter of these community-building and training activities.

The next major move was to choose a seat for the project. Jordan was finally selected as the site in a meeting on April 11, 2000, at CERN. BESSY was dismantled by Russian scientists, placed in shipping containers reminiscent of "Lego" blocks and shipped with assembly instructions to the Jordanian desert, to be stored until needed. This was made possible thanks to a direct contribution by the Director-General of UNESCO at the time, Professor Koichiro Matsuura. A major effort was also made by Dr. Khaled Toukan from Jordan, who at the time was the president of a Jordanian University and has since become the Director-General of SESAME.

Once the administrative infrastructure was in place, it was time to address the engineering and scientific aspects of the project. Technical committees designed a completely new machine. (BESSY, the old machine, would eventually be used as a boosting component to this new one.) Workshops were held to introduce regional scientists to SESAME's scientific possibilities, and committees were formed to select appropriate initial beamlines and machine parameters.



The opening ceremony of the meeting on November 19, 1995, gathered scientists from around the Middle East to discuss opportunities for scientific collaboration. The location of the meeting was a Bedouin tent in Dahab, Egypt.

The host building was constructed in Jordan. However, it remained empty due to challenges in obtaining funding. It was agreed that the running costs of the projects should be borne by the members; however, the large, one-time cost needed to construct a new machine was outside the budgets of most of the member states, particularly as many did not have a tradition of significant support for basic science. Day one seemed very far in the future.

The SESAME building in Allan, Jordan, which hosts the light source.
Photo Credit: CERN (PHOTO-201504 -069-15)

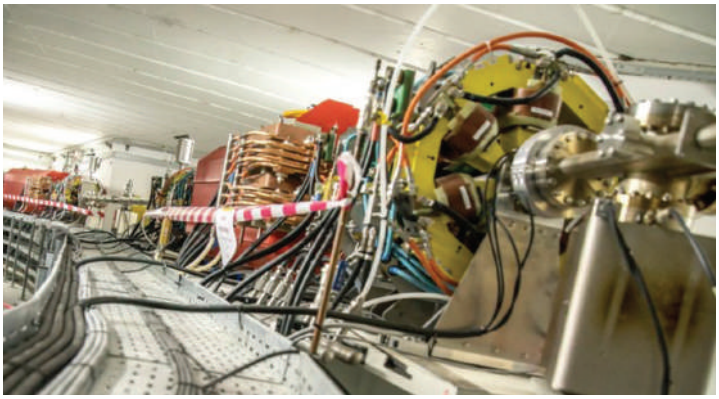
Putting Together the Pieces of the Puzzle

After the facility construction was completed, Herwig Schopper stepped down as president of the council and was replaced by another former Director-General of CERN, Professor Chris Llewellyn Smith. The new leader's main challenge was to find the funding needed to construct a new light source and to repudiate the false and harmful perception that SESAME was an old light source of little attraction to top scientists.

The absence of funding was resulting in a steady decline in morale among the local staff. The project seemed in danger. After observing this, I approached two persons in the ministry of finance in Israel. I was well received, and when I asked that Israel show an example by making a voluntary contribution to SESAME of $5 million to build a new light source, I was not shown the door. Instead they requested to come and see SESAME. After their visit, Israel agreed to contribute the requested funds on the condition that others join them.

Each member of the unlikely coalition consisting of Iran, Israel, Jordan and Turkey pledged an extra $5 million for the project in an agreement signed in Amman. This encouraged the present Director-General of CERN, Rolf Heuer, to convince the EU to dedicate five million euros to the project in addition to approximately three million euros which were previously directed to the project from a bilateral EU-Jordan agreement. Professor Fernando Ferroni, president of the National Institute for Nuclear Physics (INFN) in Italy also came on board by pledging five million euros, more than two million of which were already passed on to SESAME. Many leading labs worldwide, in a heartwarming expression of support for the project and its spirit, have donated equipment for future beam lines as well as fellowships for training young scientists and engineers. With their help, SESAME has crossed a threshold, and it is very likely that the high-quality, 2.5 GeV light source will start operation during 2017. The magnets and girdles are now real, hard steel - I touched them at CERN where they were being assembled by joint teams of CERN and SESAME. It was a very emotional moment for me to experience this idea turning into reality.

There is also steady progress in preparing two beamlines to work at first light. One is planned to be an X-ray absorption fine structure/X-ray fluorescence (XAFS/XRF) spectroscopy beamline and the other to be an infrared (IR) spectromicroscopy beamline for research.



The magnets assembled in the ring at SESAME in 2017.
Photo Credit: Noemi Caraban Gonzalez / CERN

Let me now end with some general words. Many individuals in the region and beyond have taken their people to a place their governments most likely never dreamt or planned to reach. However this saga ends, we have proven that the people of the region have in them the capability to work together for a common cause. Thus, the very process of building SESAME has become a beacon of hope to many people in our region.

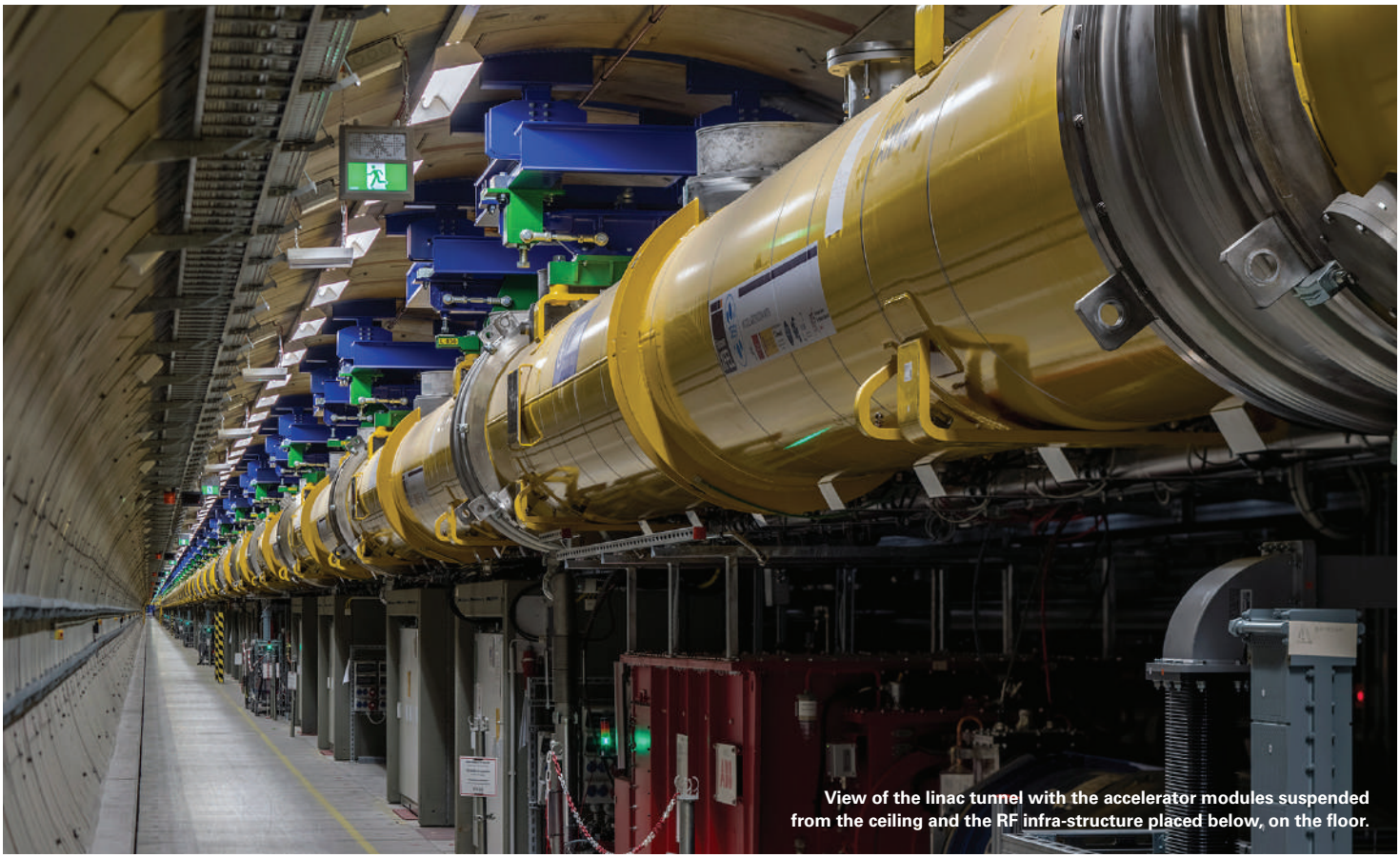
The time is approaching to match this achievement with high-quality scientific research. This will be the responsibility of SESAME in the years to come. Rolf Heuer has agreed to be the next president of the council, and I have complete confidence that with him the machine will perform excellently. I dream that work worthy of a Nobel prize will be performed at SESAME by a joint effort of scientists from my region.

Brilliant Beams Produced by the European XFEL

Hans Weise and Winfried Decking
Deutsches Elektronen-Synchrotron (DESY)

The European X-ray Free Electron Laser (XFEL) now entering operations in Hamburg, Germany, will generate 27,000 ultrashort X-ray flashes per second with a brilliance one billion times higher than the best conventional X-ray sources. The outstanding characteristics of the facility will open up completely new research opportunities for scientists and industrial users. In close cooperation with nearby DESY and other organizations worldwide, the European XFEL is a joint effort between many countries. Seventeen European institutes contributed to the accelerator complex[1]. The largest contributions were from DESY (58 %), which also coordinated the design, construction and commissioning of the accelerator complex.

The development of the European XFEL is a marvelous example of the synergies in accelerator R&D between the high-energy physics and light-source communities. In 1990, the TESLA collaboration was founded by key players of the superconducting radiofrequency (SRF) accelerator community, and among its challenges was to make SRF cavities more affordable. DESY offered to host essential infrastructure as well as a test facility to operate newly designed accelerator modules housing eight standardized cavities. The first module was built in the mid-1990s in collaboration with many of the later contributors to the European XFEL. The first electron beam was accelerated in 1997, roughly at the time when DESY started to work on the detailed design of a VUV free-electron laser (today known as the FLASH facility). The recently commissioned European XFEL, proposed in 2001, is now using almost 100 of the mentioned accelerator modules. The 1.4 km-long linac accelerates electrons in a highly efficient manner. The machine uses TESLA technology at a large scale[2].



View of the linac tunnel with the accelerator modules suspended from the ceiling and the RF infra-structure placed below, on the floor.

Facility Layout

The European XFEL, measuring 3.4 km in length, begins with the injector, which comprises a normal-conducting RF electron gun generating high charge, low emittance bunches. This is followed by a standard superconducting eight-cavity XFEL accelerator module, which takes the electron bunch up to an energy of around 130 MeV. A harmonic 3.9 GHz accelerator module (provided by INFN and DESY) is used to further manipulate the longitudinal beam profile. In addition, a laser heater provided by Uppsala University increases the uncorrelated energy spread. At the end of the injector, 600μs-long electron bunch trains of typically 500pC bunches are available, well-prepared for increasing the bunch peak current in a series of magnetic chicanes compressing the individual bunches.

Once in the main linac tunnel of the European XFEL, the electron beam is accelerated in three sections separated by bunch compressors. The first consists of four superconducting XFEL modules and presents a fairly modest gradient (far below the XFEL design gradient of 23.6 MV/m). The second linac section consists of 12 accelerator modules, from which the beam emerges with a relative energy spread of 0.3% at 2.4 GeV. The third and last linac section consists of 80 accelerator modules with an installed length of just less than 1 km. The bunch-compressor sections between the three main linac sections include four dipole magnets, further focusing elements and beam diagnostics.

Taking into account all installed main-linac accelerator modules, the achievable electron beam energy is above the European XFEL design energy of 17.5 GeV, although the exact figure will depend on the optimization of the RF control. The complete linac is suspended from the ceiling, which also holds the transport, collimation, and distribution beam lines at the main linac tunnel end. This keeps the tunnel floor free for transport and for the installation of electronics. During accelerator operation, the electrons are distributed via fast kicker magnets into one of the two electron beamlines that feed several photon beamlines in a fan-shaped tunnel. Here, undulators provide X-ray photon beams for two different experiments, with two experiments set up at three beamlines during initial operation.

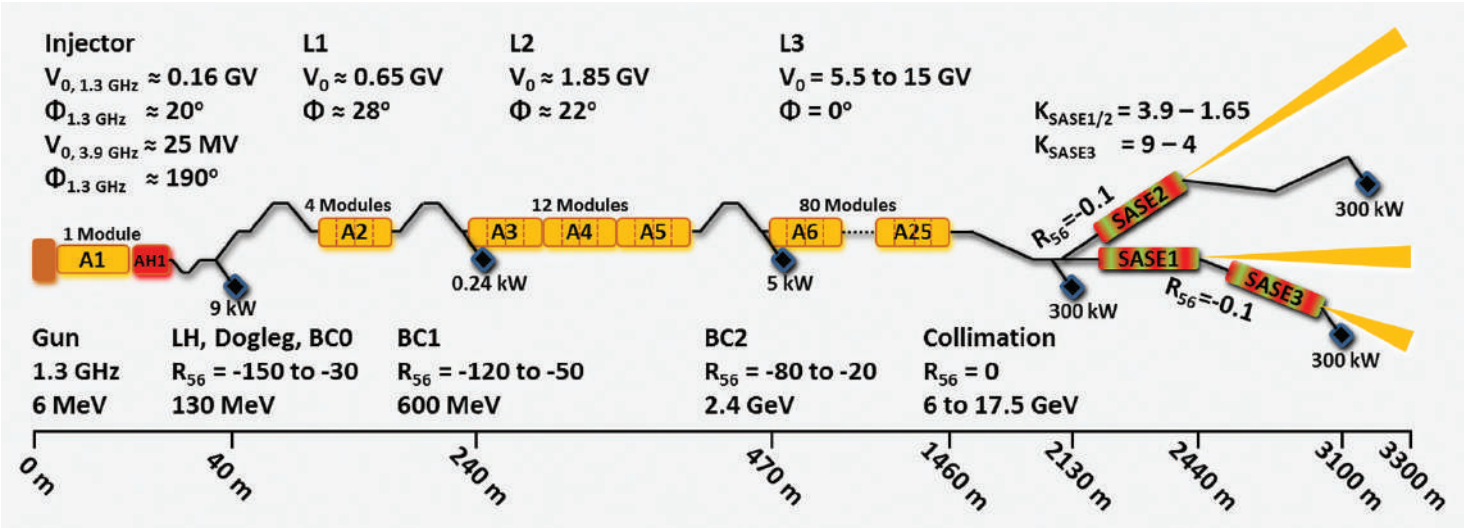
Production Challenges

DESY, which had responsibility for the construction and operation of the particle accelerator, developed a scheme in which collaborators could contribute in-kind, either by producing sub-components or by assuming responsibility for module assembly or component testing. A quite sophisticated supply chain was established, and the pioneering work at FLASH provided invaluable help in dealing with initial challenges. More than 100 modules were needed (including pre-series), and although they were based on a prototype developed for the TESLA linear collider, they had to be modified for large-scale industrial production. Finally, the superconducting accelerator modules for the European XFEL linac were contributed by DESY, CEA Saclay and LAL Orsay in France, INFN Milano in Italy, IPJ Swierk and Soltan Institute in Poland, CIEMAT in Spain and BINP in Russia[3].

A standard accelerator module contains eight superconducting cavities, each supplied by one RF power coupler and a superconducting quadrupole package, which includes correction coils and a beam position monitor. Each module also contains cold vacuum components such as bellows and valves, and frequency tuners. During the R&D and project preparation phases, less than one accelerator module per year was assembled. Thus it took a factor 30 increase in production rate to build the European XFEL. Two European companies—Research Instruments in Germany and Zanon in Italy—shared the task of producing 800 superconducting cavities from solid niobium. Cavity string and module assembly took place at CEA Saclay/IRFU based on completely new infrastructure called the "XFEL village". Assembly was directly impacted by the availability of all accelerator module sub-components, and any break in the supply chain was seen as a risk for the overall project schedule. In the end, a total of 96 successfully tested XFEL modules were made available for tunnel installation within a period of just two years.

The operation of the superconducting accelerator modules also requires extensive dedicated infrastructure. DESY provided the RF high-power system and developed the required 10 MW multi-beam klystrons with industrial partners. A total of 27 klystrons, each supplying RF power for 32 superconducting structures or four accelerator modules, were ordered from two vendors. Precision regulation of the RF fields inside the accelerating cavities, which is essential to provide a highly reproducible and stable electron beam, is achieved by a powerful control system developed at DESY. BINP Novosibirsk produced and delivered major cryogenic equipment for the linac, while the cryogenic plant itself, an in-kind contribution of DESY, guarantees pressure variations will stay below 1%. The largest visible contributions to the warm beamline sections are the more than 700 beam transport magnets and the 3-km vacuum system in the different sections. While most of the magnets were delivered by the Efremov Institute in St Petersburg, a smaller fraction was built by BINP Novosibirsk and completed at Stockholm University. Many meters of beamline, be it simple straight chambers or the more sophisticated flat bunch compressor chambers, were also fabricated by BINP Novosibirsk.

State-of-the-art electron beam diagnostics are of essential importance for the success of the European XFEL. Thus, 64 screens and 12 wire scanner stations, 460 beam position monitors of eight different types, 36 toroids and six dark-current monitors are distributed along the accelerator. Longitudinal bunch properties are measured by bunch compression monitors, beam



Schematic of beamline layout for the European XFEL

arrival monitors, electro-optical devices and transverse deflecting systems. Major contributions to the electron beam diagnostics came from PSI in Switzerland, CEA Saclay in France, and from INR Moscow in Russia.

Successful Commissioning

Commissioning of the European XFEL accelerator began in December 2016 with the start of the cool-down of the complete cryogenic system. First beam was injected into the main linac in January 2017, and by March bunches with a sufficient beam quality to allow lasing were accelerated to 12 GeV and stopped in a beam dump after the 2-km-long accelerator. After passing this beam through the SASE1 undulator, first lasing at 0.9 nm photon wavelength was observed on May 2. Further improvements to the beam quality and alignment led to lasing at 0.2 nm on May 24. More than 90% of the installed accelerator modules are now in RF operation, with effective accelerating gradients reaching the expected performance in fully commissioned stations[4].

Meanwhile, first user operation was started in September 2017 with two experimental stations. The photon wavelength was set to about 0.13 nm and 10 to 300 pulses per second were delivered with a SASE intensity of 400-1000 μJ per pulse. The electron energy was 14 GeV with always one of the 20 RF stations in standby. This allowed for a high up-time already in this early phase of operation. During these early experiments the interaction between accelerator operation, photon beam production and light use was put to a successful first test.

The European XFEL is one of the largest accelerator-based research facilities in the world, and the underlying accelerator technology could only be built due to the great collaborative effort accompanied by an immense team spirit among the involved partners. DESY and its collaborators extended its use by constructing and now operating the world's longest superconducting linac. Because of the enormous flexibility in electron bunch time structure, the development of free-electron lasers was connected with superconducting accelerator technology from early on; examples can be found at Stanford University, Darmstadt University and Dresden Rossendorf, Jefferson Laboratory, and DESY. The first hard X-ray SASE free-electron laser, the Linac Coherent Light Source (LCLS) at SLAC in the U.S., was based on a normal-conducting accelerator. The upgrade to LCLS-II now aims for continuous wave operation using 280 superconducting cavities of essentially the same design as those of the European XFEL. Improvements to the superconducting technology were done to further reduce the cryogenic load of the accelerator structures. New techniques (e.g., nitrogen doping and infusion) developed by Fermilab and other LCLS-II partners are essential. Established procedures and expertise with series production will benefit future FEL user operation. The now existing European SRF expertise and collaboration scheme also sketches out a mechanism for a European in-kind contribution to a Japan-hosted International Linear Collider.

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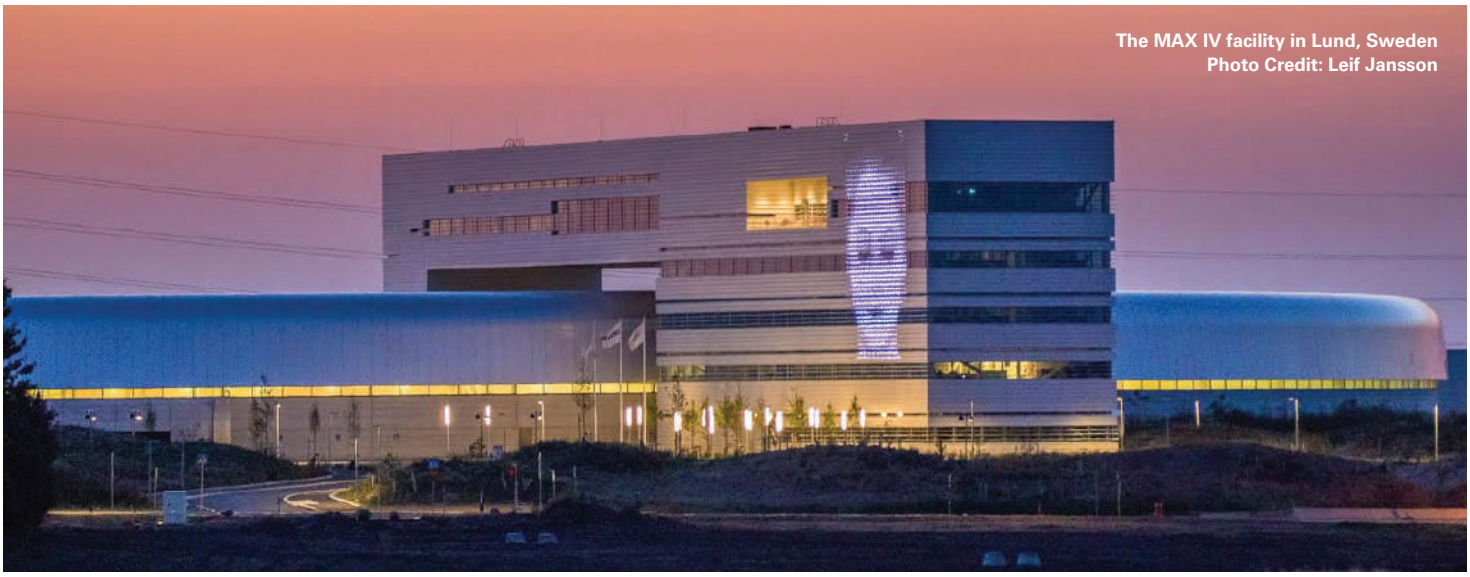
MAX IV: The First Year

Pedro F. Tavares
MAX IV



The MAX IV facility in Lund, Sweden
Photo Credit: Leif Jansson

MAX IV Laboratory is the new Swedish national synchrotron radiation facility, located just outside the university city of Lund. MAX IV builds upon a long tradition of accelerator technology development and synchrotron radiation science conducted for nearly three decades at its predecessor facility, Max-lab, which was officially closed in December 2015. About six months later, on June 21, 2016, the inauguration of MAX IV laboratory marked the end of a six-year construction period and over a decade of efforts to create a facility that could provide the Swedish and international scientific communities with the first ultra-high-brightness light source to make use of the multi-bend achromat (MBA) lattice, an approach that in the past few years has become increasingly common in new storage-ring-based light source project proposals in the Americas, Europe, and Asia.

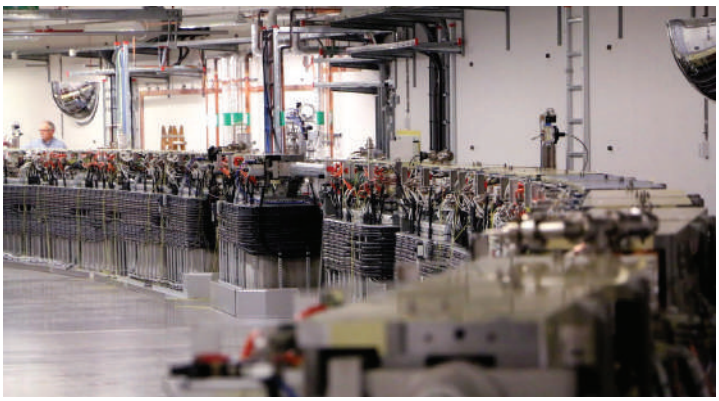
The core of the MAX IV facility[1] consists of three electron accelerators and their respective synchrotron radiation beamlines. Two are electron storage rings that operate at different energies (1.5 GeV and 3 GeV) to optimally cover a wide photon energy range with short-period insertion devices, while the third, a linear accelerator, acts as a full-energy injector into both rings and provides electron pulses as short as 100 fs to produce X-rays by spontaneous emission in the undulators of the short-pulse facility.

The 3 GeV ring is optimized for the production of high-brightness, hard X-ray beams and features a 20-fold, seven-bend achromat lattice, reaching a bare lattice emittance of 0.33 nm rad. Such a low emittance in only 528 m of circumference is achieved through the use of a compact magnet design, narrow low-conductance NEG-coated copper vacuum chambers, and a 100 MHz RF system with passively operated 3rd harmonic cavities for bunch lengthening.

At the time of inauguration, now a little over a year ago, the full energy injector linac had been in operation for more than a year. The 3 GeV ring had demonstrated up to 200 mA stored beam current, and was providing routine beam delivery (typically at lower currents, around 10 mA) for radiation safety surveys and commissioning of the first two beamlines.

During the past year, three additional insertion devices were installed, while accelerator performance was further characterized and consistently improved. In particular, a diagnostics beamline imaging visible and near infra-red radiation from a bending magnet was used to confirm the expected ultra-low emittance. Furthermore, the storage ring linear lattice was improved using the standard LOCO technique with beta beats having been reduced from ± 20-30% down to ± 2-3%. Correction of coupling allowed a reduction of the residual vertical dispersion to less than 0.6 mm RMS, and vertical emittances down to 3 pm rad have been observed.

Careful trimming of the ring optics, coupling, and linac-to-ring transfer line settings allowed demonstration of injection efficiencies higher than 90% even with insertion device gaps closed down to 4.5 mm aperture, leading to the establishment of top-up injection with beamline shutters open, for which the required radiation safety permits have been obtained. Orbit stability in both the long and short terms has been recorded and followed up from the early stages of commissioning, and reveal a very quiet beam. Indeed, even with only the slow orbit feedback current implemented (running at an effective 0.25 Hz rate), measurements of the fast (10 kHz) data streams generated by the 40 BPM electronics flanking the long straights around the ring reveal frequency-integrated (from 0.1 Hz to 100 Hz) RMS orbit oscillations below 710 nm in the horizontal plane and below 170 nm vertical plane (corresponding to 1.3% and 5.5% of the respective RMS beam sizes at the positions of the BPMs).



The MAX IV 3 GeV ring tunnel. Photo credit: Madelein Schoug

Vacuum conditioning of the NEG-coated chambers has proceeded at the expected pace as confirmed by the fall in dynamic pressure rise as a function of accumulated beam dose, and more importantly, by the evolution of beam lifetime. In fact, scraper measurements indicate that the product of gas scattering lifetime and current reached 7 A h at 160 A h of accumulated. As the current in the ring went up, a number of hot spots in the ring vacuum chambers were identified, and the causes were tracked down to either chamber installation or production errors. A program to replace the faulty chambers is ongoing with the goal to overcome the present limitations (estimated at ~ 190-200 mA) to stored beam current by mid-2018.

Up to about 9 mA of single-bunch current could be stored without signs of limitations by transverse instabilities, and longitudinal coupled-bunch instabilities have been kept under control by a longitudinal feedback system. So far, only a weak actuator (striplines operated in common mode) has been available for the longitudinal feedback, and a fully longitudinally stable beam could be achieved up to about 100 mA with harmonic cavities detuned. When the harmonic cavities are engaged, they provide bunch lengthening and improve stability, with flat-potential conditions being expected at higher currents. Measurements of the spectrum of an in vacuum undulator around its 15th harmonic revealed about a factor 2 increase in energy spread (compared to the natural energy spread) when the harmonic cavities are tuned in at about 160 mA beam current.

The first six months of routine synchrotron radiation delivery by the 3 GeV ring resulted in 92% source availability, the biggest causes for accelerator downtime being infrastructure problems (mainly cooling and air conditioning system failures), vacuum trips in beamlines that were being exposed to synchrotron light for the first time and RF system trips.

Short-term improvement plans for the 3 GeV ring include the ongoing installation of a multipole injection kicker (designed and built through a collaboration with the SOLEIL team and based on a design originally proposed at BESSY), which will reduce the perturbations seen by users during top-up injections. Moreover, a recently installed longitudinal kicker cavity is expected to improve the performance of the longitudinal bunch-by-bunch feedback system. In the mid and long term, a number of upgrades and improvements are contemplated. Higher-brightness beams can be achieved either by pushing the present 3-GeV ring lattice within the hardware constraints of the existing magnets or by more radical magnet replacements and lattice designs that have been initiated with the long-term goal of achieving the diffraction limit at 10 keV (i.e., 10 pm rad horizontal emittance) within the 528 m circumference of the MAX IV 3 GeV ring tunnel. In the 1.5 GeV ring, single-bunch operation and timing modes are in preparation.

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How Small Accelerator Experiments Can Unravel the Mystery of Dark Matter

Marco Battaglieri and Natalia Toro
Istituto Nazionale di Fisica Nucleare and SLAC National Accelerator Laboratory

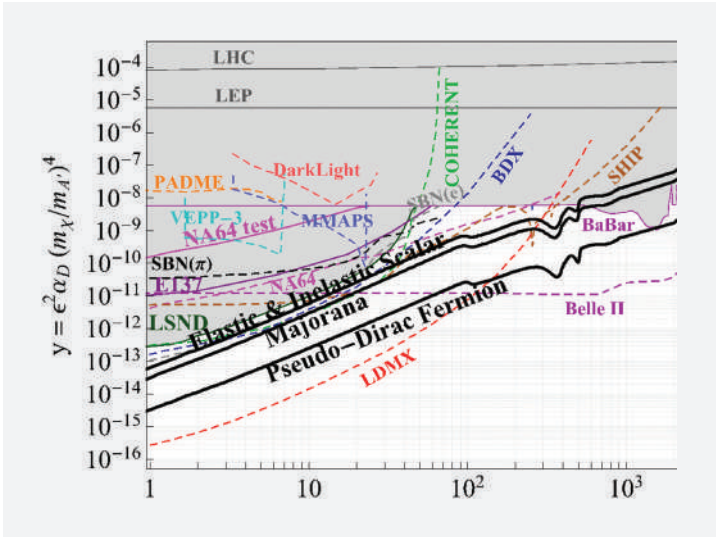
From the first discoveries of hadronic resonances in the 1960s, to the empirical demonstration of the nature of the weak and strong interactions in the1970s and 80s and the discovery of the Higgs boson in 2012, accelerator-based experiments have been key to unraveling nature's building blocks and their interactions. But cosmological data has revealed a big problem with the Standard Model: it only accounts for a quarter of the matter that makes up our universe.

The remaining "dark matter" (DM) has been observed indirectly through gravitational lensing and galactic rotation curves, and its effects on the very early universe inferred from primordial nucleosynthesis and the cosmic microwave background. These measurements quantify the gravitational effects of dark matter, revealing its abundance, its primordial origin, and that its constituents are different from the building blocks of ordinary matter. The identity and origin of the dark matter are perhaps the greatest mysteries in fundamental science today. Could accelerator-based experiments once again open the door to solving them?

The defining challenge to this program is the weakness of dark matter's interactions. The only interactions we know dark matter possesses are gravitational; even if its constituents interact sufficiently to be produced at accelerators, they would not announce their presence through tracks or showers in a detector. But similar obstacles have been surmounted before: accelerator-based experiments offer the best measurement of a neutrino mixing angle—θ_{13}—despite the weakness of neutrino interactions; the invisible width of the Z boson has also been precisely measured, and invisible decays of the Higgs boson are quite constrained. Dedicated searches for dark matter can exploit similar techniques.

Most searches for dark matter, either at accelerators or in underground laboratories, start from the simple and conservative premise that the constituents of dark matter need not be so different from those of the Standard Model—new matter, possibly interacting via a new force, but with a fundamental structure analogous to the Standard Model and at similar mass scales. Indeed, this picture suggests a natural possibility for the origin of the dark matter we see today: In the hot, early universe, dark matter interactions with familiar matter would have brought it into thermal equilibrium; as the universe cooled, these interactions

Accelerator-based Searches and Minimum Signals for Thermal Relic



Minimum interaction strengths motivated by thermal relics (black lines) vs. current sensitivity of accelerator-based searches (gray shaded) and proposed experiments (dashed curves), adapted from [2]

would have slowed down, leaving a residual abundance of dark matter particles. This "thermal relic" hypothesis goes hand-in-hand with the idea that dark matter possesses Standard-Model-like interactions at Standard-Model-like scales, and implies a precise prediction for the dark matter annihilation cross-section, which is an important benchmark for dark matter searches.

The most familiar embodiment of these ideas is the weakly interacting massive particle, or WIMP—originally defined as a new particle of TeV-scale mass and charged under the weak force of the Standard Model, although the term is now used more generally to refer to any particle of weak-scale mass with sizeable couplings to ordinary matter.

A related, less constrained possibility is that dark matter resides near the mass scales of the stable Standard Model particles—roughly between the electron and proton masses. For dark matter in this mass range, the "thermal relic" picture motivates a new force through which dark matter couples to ordinary matter—a force whose coupling to familiar matter is expected to be miniscule (as can arise from quantum corrections to the theory) and therefore beyond the reach of past experiments.

Testing this possibility does not require particularly high beam energies, but instead motivates experiments that draw on high-intensity beams or high-precision measurements to detect very rare interactions. The last decade has seen a surge of ideas for such searches, exploiting data from past experiments as well as new experimental proposals[1,2]. Most recently, the community gathered to survey opportunities for small experiments in the United States and abroad at the workshop "Cosmic Visions: New Ideas in Dark Matter"[2].

Proposed searches would look for dark matter in two very different ways: some would look for the scattering of dark matter particles produced when a high-intensity beam impinges on a dump (similar to the signal used in accelerator-based neutrino physics). Indeed, the best constraints to date on DM below a few hundred MeV come from reanalyses of old beam-dump data (E137 and LSND); new proposals can improve this sensitivity by using higher-energy and/or higher-intensity beams (often parasitically), and detectors that are larger, closer to the dump, or more sophisticated. The other major class of experiments infer dark matter production from the kinematics of some or all visible products of a reaction (more akin to invisible Higgs-decay searches, but at lower energies). For example, the best present sensitivity to GeV-scale DM comes from a missing-mass search at BaBar at SLAC National Accelerator Laboratory, with significant opportunities for missing-mass and missing-energy searches at GeV-scale, fixed-target experiments using electron or positron beams.

These proposals are complementary and have widely varied beam requirements. For example, DM scattering searches rely on dumping a high-current proton or electron beam, ideally at multi-GeV energy, and require a detector site downstream of the dump. Beam-unrelated backgrounds are lowest with a pulsed beam, but suitably intense electron beams are continuous wave (CW). At the other extreme, missing energy/momentum searches require a beam with at most a few electrons impinging on the detector at a time (which must be spatially separated). Exploratory measurements can be achieved using test beams, but high-performance experiments require CW beams with pA-scale beam current. Many mediator searches call for higher-current CW electron beams, such as those available at Thomas Jefferson National Accelerator Facility, impinging on thin targets, while some fixed-target missing-mass searches require positron beams.

For this reason, proposals for small experiments draw on a wide variety of existing accelerator facilities within the US (e.g., Cornell University's CESR, Fermi National Accelerator Laboratory's BNB, BooNE, and Main Injector, JLab's CEBAF and LERF, Oak Ridge National Laboratory's SNS, and SLAC's LCLS-II) and abroad (e.g., BINP, CERN, KEK, LNF, and MESA).

Accelerator searches play an essential role in the search for sub-GeV dark matter. Of particular interest, the simple "thermal relic" hypothesis motivates, for a given dark matter mass, a minimum production yield in accelerator-based experiments that varies slightly depending on the DM spin (shown as black lines in Figure 1). Of the four possible DM-spin scenarios shown, all except the "elastic scalar" have velocity- or loop-suppressed scattering cross-sections, making direct detection difficult even in principle. Accelerators are, therefore, uniquely suited to discover (or exclude) this mechanism.

Remarkably, the ideas being developed now promise to test this possibility robustly for DM lighter than a few GeV. If any DM candidate is found, these experiments offer a clear path to disentangle the particle properties. The "new Standard Model" of the dark sector may be within reach!

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A Brief History of Fermilab

Katie Yurkewicz
Fermi National Accelerator Laboratory

On June 15, 1967, the first few employees of the National Accelerator Laboratory showed up to work in temporary offices in Oak Brook, Illinois. Under the direction of Robert R. Wilson, those pioneers worked tirelessly to build a brand-new laboratory at the forefront of particle physics. Fifty years later, Fermilab celebrates its history of discovery and innovation and looks ahead to a bright future. Travel month-by-month through 50 years of Fermilab milestones and learn how the laboratory celebrated its golden anniversary—and how you can still be part of the commemoration.

January / In Fermilab history:

The first task of Fermilab's first employees was to design a 200 GeV accelerator and develop a plan for its construction and the operation of the lab that would run it. In January 1968, that plan was published as the National Accelerator Laboratory Design Report. A major step toward achieving that design was taken on January 30, 1970, when workers moved the first linear accelerator tank into the newly finished tunnel.

Celebrating in 2017:

Fermilab's 50th anniversary program provided opportunities for different groups to celebrate Fermilab's past, present, and future. In January, the lab's employees kicked off the year; a special science-themed musical performance drew a sell-out crowd to the lab's Arts Series; and theoretical physicist Chris Quigg presented "Fermilab's Greatest Hits".

February / In Fermilab history:

Robert Wilson agreed to direct the new laboratory on February 28, 1967. Five years later on February 12, 1972, the experimental program began when experiment E-36, Small Angle Proton-Proton Scattering, began testing equipment in the lab's newly achieved 100 GeV beam.

Celebrating in 2017:

Fermilab has been collecting anecdotes and stories about the lab's first half-century throughout 2017. You can read or view them on our 50th anniversary website, 50.fnal.gov.

To view additional images, video, and stories of Fermilab's 50 year history plus information about current innovations and future discoveries, visit:

50.fnal.gov

March / In Fermilab history:

The Main Ring accelerator achieved its design energy of 200 GeV on March 1, 1972, ahead of schedule and under its $250 million budget. Design for the Main Ring's successor began later that year, and the last magnet was installed in the Tevatron on March 18, 1983. Twelve years later on March 2, 1995, the CDF and DZero collaborations announced the top quark discovery.

Celebrating in 2017:

Lab employees, users, and visitors came together to record at least one photo every single day of 2017 in the Daily Image from Fermilab.

April / In Fermilab history:

Robert Wilson's vision for the new laboratory was a place where science, technology, and art are connected to create a beautiful setting that inspires beautiful science. Wilson Hall, the lab's striking 16-story central building, which was completed on April 5, 1973, embodies that vision.

Celebrating in 2017:

April saw the launch of a countdown of 50 of Fermilab's top discoveries and innovations that ended with the lab's birthday on June 15.

May / In Fermilab history:

The lab was dedicated in honor of Nobel Prize-winning physicist Enrico Fermi on May 11, 1974. The laboratory's pioneering foray into experimental particle astrophysics took off on May 9, 1998, when the Sloan Digital Sky Survey received first light. And Fermilab's future in long-baseline neutrino physics kicked off on May 31, 2000, with the groundbreaking ceremony for the Neutrinos at the Main Injector (NuMI) beamline.

Celebrating in 2017:

Browse milestones and highlights from Fermilab's first 50 years through an interactive, online timeline (50.fnal.gov/timeline/).

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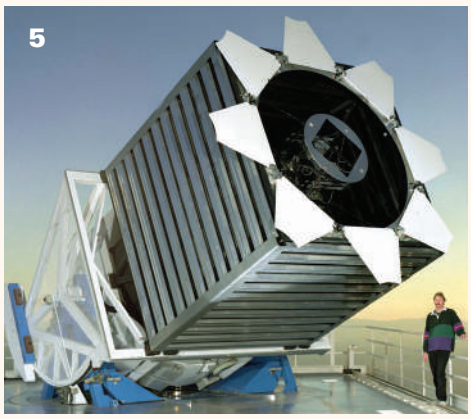
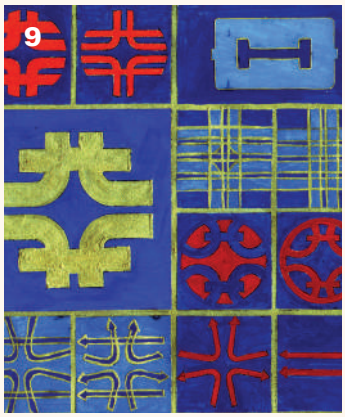
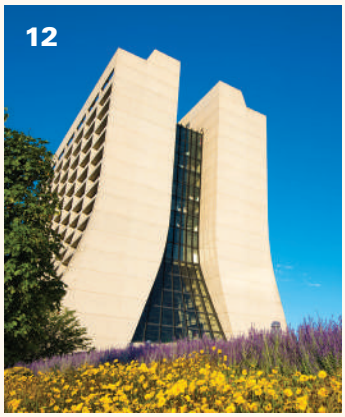






1 Moving first Linac Accelerating Tank into Linac Tunnel, 01/30/1970 // **2** Unidentified social event, 03/01/1972 // **3** Experiment 36 Personnel, 04/18/1973 // **4** Leon Lederman receives his Nobel Prize, 1989 // **5** Sloan Digital Sky Survey 2.5-meter telescope, 04/11/2000 // **6** Byron Lundberg and Regina Rameika in front of the E872 (DONUT) detector, 06/12/2000 // **7** J. Chamberlain and T. Asher with Tevatron magnet in E Sector of Main Ring Tunnel, 11/09/2001 // **8** Employee 50th birthday group photo // **9** Detail of the drawings and paintings by Angela Gonzales showing the evolution of the Fermilab logo mark // **10** LBNF/DUNE groundbreaking at Sanford Underground Research Facility // **11** Fermilab 50th Anniversary Community Open House // **12** Front of Wilson Hall with flowers in early morning, 07/31/2017

Images 4, 5, 7, 8, 10, 12: Photo Credit: Reidar Hahn
Image 11: Photo Credit: Marty Murphy

June / In Fermilab history:

June 15, 1967, the day the first employees showed up to work in Illinois, marks the lab's birthday. The discovery of the upsilon particle—and thus the bottom quark—was announced on June 30, 1977. In June 1999, the Main Injector synchrotron was dedicated, ushering in a new era for the Fermilab accelerator complex.

Celebrating in 2017:

The Fermilab 50th Anniversary Symposium and Users Meeting brought hundreds of people from the scientific community together to celebrate the past and future of particle physics. Lab employees celebrated Fermilab's official 50th birthday on June 15.

July / In Fermilab history:

July brought Fermilab three new directors, with John Peoples, Michael Witherell and Pier Oddone beginning their terms in 1989, 1999, and 2005, respectively. The DONUT collaboration announced the first direct evidence for the tau neutrino on July 21, 2000. Fermilab scientists joined their colleagues on the CMS and ATLAS experiments at the Large Hadron Collider to announce the discovery of the Higgs boson on July 4, 2012.

Celebrating in 2017:

The CERN Courier and Symmetry Magazine both published articles commemorating the lab's 50th year, and a book of essays from scientific, academic, and government leaders was published.

August / In Fermilab history:

Fermilab's first experimental results were published on August 21, 1972, when a paper summarizing the results of E-141, the Study of pp Interactions in the 30-Inch Hydrogen Bubble Chamber, appeared in Physical Review Letters. On August 16, 1983, a groundbreaking ceremony was held for the Antiproton Source.

Celebrating in 2017:

Fermilab's pioneering work in the connections of art and science were also celebrated in 2017, including an exhibit on the works of Angela Gonzales, the artist hand-picked by Robert Wilson to develop Fermilab's visual aesthetic.

September / In Fermilab history:

Fermilab employees moved to the lab's permanent home in September 1968, and the first six bison followed a year later. The Neutron Therapy Facility treated its first patient on September 7, 1976. On September 12, 2012, the Dark Energy Survey received its first light, and just shy of a year later the lab welcomed its sixth director, Nigel Lockyer.

Celebrating in 2017:

On Saturday, September 23, Fermilab welcomed 10,000 members of the public behind the scenes in the largest Open House at the laboratory in 20 years.

October / In Fermilab history:

October was a prize-winning month for Fermilab directors, with President Richard Nixon announcing on October 3, 1973, that Robert Wilson would receive the National Medal of Science, and Leon Lederman receiving the call on October 19, 1988, informing him that he would share the Nobel Prize in physics for the discovery of the muon neutrino.

Celebrating in 2017:

While Fermilab hosted a number of on-site events to mark its 50th anniversary, the lab also used the historic milestone to improve and expand its off-site public outreach program, adding engineering, computing, and neutrino science to its popular classroom presentation offerings, attending local festivals, and hosting events in downtown Chicago.

November / In Fermilab history:

November was a milestone month for neutrinos at Fermilab. The first neutrinos were detected at Fermilab in November 1971 by the E-21 experiment; the NOvA far detector in Minnesota detected its first neutrinos on November 12, 2013; and the MicroBooNE liquid-argon experiment detected its first neutrinos on November 2, 2015.

Celebrating in 2017:

November 13, 2017, marked the dedication of an IEEE Milestone Award for Fermilab's pioneering role in transitioning the use of superconducting wire and cable from a laboratory endeavor to the industrial scale through the construction of the Tevatron particle collider.

December / In Fermilab history:

The last month of the calendar year marks the first of Fermilab's major historical milestones. On December 7, 1966, the town of Weston, Illinois, was selected as the site of the National Accelerator Laboratory, beating out 125 other proposals. The rest, as they say, is history.

Celebrating in 2017:

Fermilab's 50th year included research milestones as well as commemorative events. Groundbreaking took place for the Long-Baseline Neutrino Facility, the Muon g-2 experiment received its first beams of muons, the ICARUS detectors arrived at Fermilab from CERN for the Short-Baseline Neutrino Program, and the Dark Energy Survey spotted an optical counterpart to the third gravitational wave ever to be recorded. Fermilab is well positioned for another half-century at the forefront of discovery.

Machine Learning for Accelerator Applications

D. Ratner, Editor *SLAC National Accelerator Laboratory*

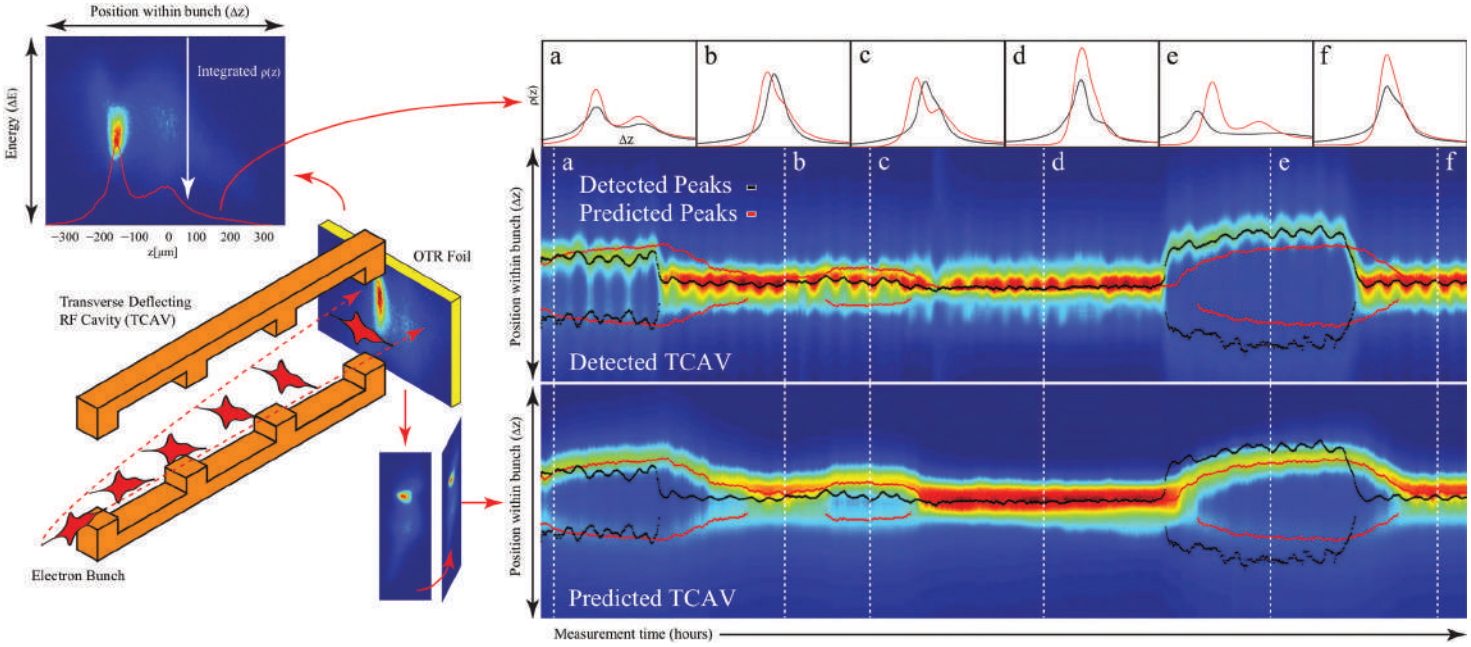
Contributing Authors: I. Agapov (DESY), S. Biedron (EA), Daniel Bowring (FNAL), A.L. Edelen (CSU/FNAL), X. Huang (SLAC), R. Ischebeck (PSI), S. Milton (EA), T. A. Mohayai (IIT/FNAL), A.-S. Müller (KIT), D. Neuffer (FNAL), A. Scheinker (LANL), P. Snopok (IIT/FNAL), S. Tomin (European XFEL), J. Wu (SLAC), M. Yan (KIT)

Modern particle accelerators are capable of generating vast amounts of data, making them increasingly attractive for machine learning (ML) applications. Though accelerator physicists and engineers have experimented with ML for decades, recent advances in methods and computing power, coupled with the availability of better training data sets has led to a jump in interest. Here we detail a few of the many examples of machine learning already taking place at accelerators worldwide.

Free electron laser (FEL) operation requires fine control of the electron beam to enable what is fundamentally an instability. As a result, tuning an accelerator to optimize photon beam parameters (pulse energy, bandwidth, etc.) requires substantial machine time and resources. Efforts in controlling electron beams with machine learning have been developed and tested at several electron machines over the past ten years[1]. One recent example is Bayesian optimization, which is attractive due to the ability to learn machine models from archived data and better exploit exploration and exploitation in the tuning process. SLAC National Accelerator Laboratory is using this approach to guide a search of parameter space by training Gaussian process models on archived and simulated data[2]. Similarly, Deutsches Elektronen-Synchrotron (DESY) is using classification, clustering and model selection to identify optimal tuning strategies and select initial parameter estimates. DESY has also spearheaded the development of Ocelot, a software platform dedicated to automation and optimization[3]. SwissFEL at the Paul Scherrer Institut in Switzerland is working with Eidgenössische Technische Hochschule Zürich (ETHZ, Swiss Federal Institute of Technology in Zurich) and the Karlsruhe Institute of Technology (KIT) to employ similar methods during commissioning of their X-ray FEL. Element Aero (EA) has also been pursuing rapid tuning of FELs, including those of high average power and compact designs, using a neural network control policy[4].

Though not strictly machine learning, there is also closely related work on model-independent tuning methods. These methods are capable of tuning multiple coupled parameters based on noisy, scalar measurements. The robust conjugate direction search (RCDS) method[5], developed at the Stanford Synchrotron Radiation Lightsource and already in use at multiple synchrotrons, has been successfully applied to many online accelerator optimization problems, including storage ring coupling minimization, storage ring dynamic aperture and lifetime optimization, kicker bump residual oscillation minimization, beam transport line steering and optics optimization, and FEL undulator taper optimization. Another method, extremum seeking (ES)[6], developed at Los Alamos National Laboratory, has the additional feature of handling time-varying systems. ES has been implemented in hardware at SPEAR3 to continuously minimize kicker bump residual oscillations in a time-varying lattice and also at FACET to predict destructive transverse deflecting cavity (TCAV) measurements based on non-invasive energy spread spectrum measurements.

Optimization problems can also be viewed through the framework of training optimal search policies. A recent study at SLAC applied reinforcement learning to the problem of optimizing the FEL's undulator taper[7]. In the language of reinforcement learning, spectral and pulse energy output provide a reward, clustered XTCAV images represent states, and undulator strength adjustments are actions. The optimal policies are trained from simulated data and then applied to the real machine; recent live tests doubled pulse energy from a standard smooth taper by introducing a 'zig-zag' taper. EA has tackled similar control problems through neural network models, reinforcement learning, and neural network control policies in collaboration with large accelerator laboratories such as Fermi National Accelerator Laboratory. Some examples include model-predictive control over the resonant frequency of normal-conducting cavities at Fermilab, direct incorporation of image-based diagnostics into neural-network machine models and control policies[8], rapid switching between requested operating states using neural-network control policies, and creating fast-executing surrogates of a priori accelerator models. Demonstrations of these techniques are being conducted on machines such as Fermilab's PIP-II Injector Test and the FAST photoinjector.



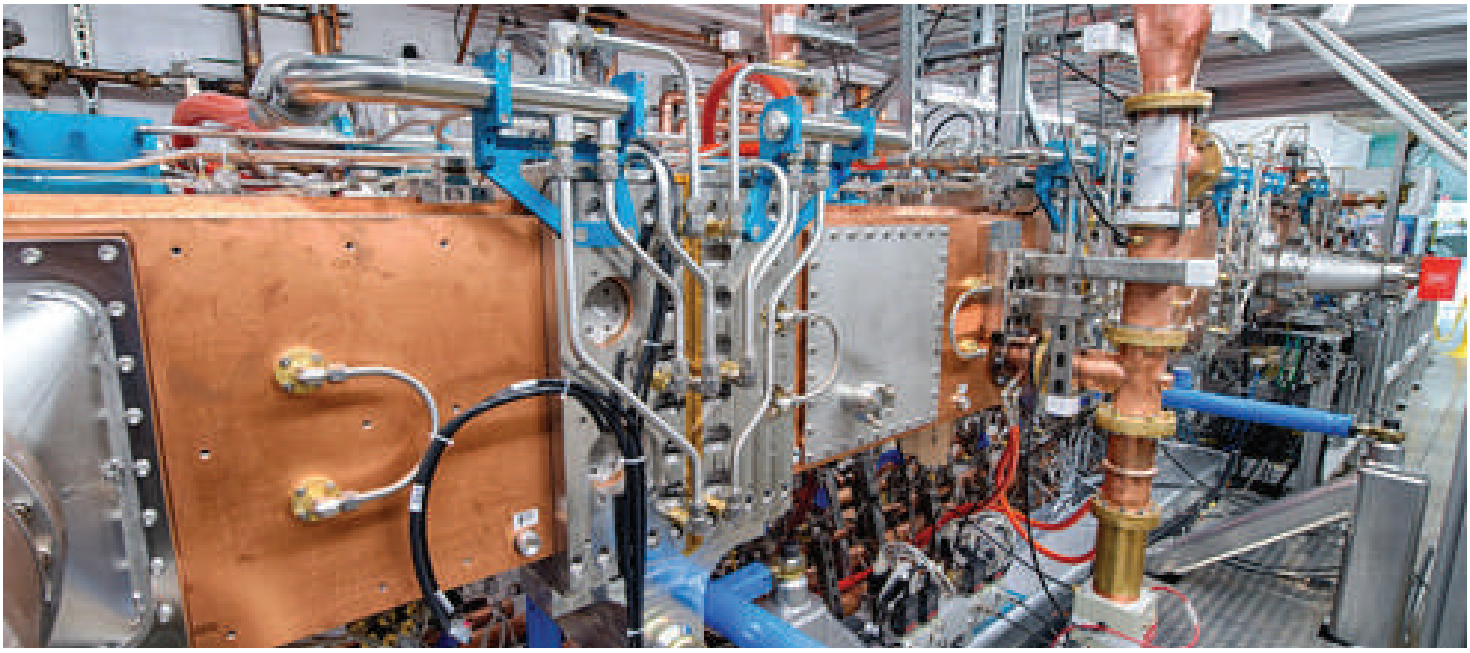
The experimental results of ES predicting and tracking the time-varying TCAV measurement at FACET

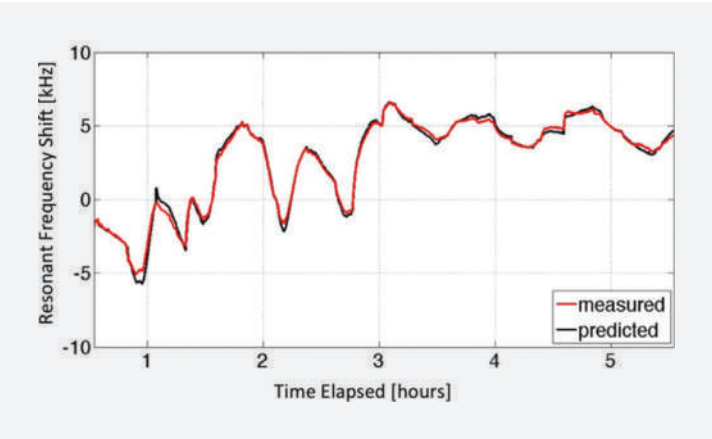
In addition to facilitating control, machine learning can also help reveal underlying physics. At the ANKA storage ring test facility at KIT, ML has been employed to understand (and at a later stage, control) the micro-bunching instability, which leads to the emission of intense but fluctuating THz radiation[9]. As a first attempt, the huge amount of data provided by various fully synchronized, high-data-throughput diagnostics (such as THz detectors, electro-optical diagnostics and the respective DAQ systems KAPTURE[10] and KALYPSO[11]) has been analyzed using both the clustering and classification algorithms of machine learning to extract knowledge on the dynamics of the small-scale microstructures. For example, the frequency and the current threshold of the fluctuation can be identified automatically from bunch-current THz radiation fluctuation spectrograms. By applying the k-means method to the longitudinal bunch profiles, the fast-varying microstructures can be revealed, which allows further investigation of their correlation to specific machine settings (e.g., RF voltage, synchrotron frequency, vacuum chamber impedance). The results of these analyses represent the figures of merit for subsequent optimization of machine parameters for strong and stable THz emission.

A second example of investigating physics through ML is Illinois Institute of Technology and Fermilab's application of an unsupervised machine learning technique known as non-parametric density estimation (NDE) to muon beam cooling[12,13]. Unlike the RMS emittance measurement which requires an assumption about the functional form of the phase-space distribution, NDE does not make any assumptions and allows the muons in the beam to 'speak for themselves.' NDE analysis enables a more detailed analysis of the evolution of the beam distribution, and therefore a more complete comparison with simulation and theory, than RMS evaluations. In particular, NDE has been used in the International Muon Ionization Cooling Experiment for precise classifications of the beam core and halo, accounting for non-linear and chromatic effects, and precise beam diagnostics in the cooling section.

Training data quality is a bottleneck for many of these ML methods. At DESY, the superconducting linear accelerator's control system generates data with MHz rate for a large number of channels; on the other hand, essential parameters whose measurements require special diagnostics could be missing. Significant attention is being paid to clean data collection and data reduction as well as generating training sets from simulations. SLAC has recently begun looking into generating training sets automatically by algorithmic labeling (e.g., "data programming") to avoid the need for labor-intensive hand labeling.

We emphasize that this is only a small taste of current ML work on accelerators, and we expect the number of applications to multiply in the next few years as advances in modern diagnostics and instrumentation lead to an increasing amount of data available for control and optimization. For example, machine protection systems based on modern computer vision, anomaly detection, and failure-prediction algorithms could be critical for high-repetition-





The resonant frequency of radio frequency quadrupoles (RFQs) needs to be controlled tightly in variable duty factor, high-power machines like Fermilab's PIP-II Injector Test. Traditional control methods such as PID are less suitable for this type of system due to the presence of transport delays, long and short thermal responses (e.g., seconds to tens of minutes), and the large disturbances created by variations in RF heating. For the PIP-II RFQ (top), a predictive control scheme using an ML model (bottom) is under development. Photo credit: Reidar Hahn

rate machines like XFEL and LCLS-II. Similarly, ML-based tuning could prove to be a critical component in switching between different operating conditions in such machines, thus enabling higher user throughput and scientific output. ML is now technologically mature enough to provide significant value to a variety of particle accelerator applications, and we expect it will soon make the transition from a research tool to a prerequisite for the accelerators of the future.

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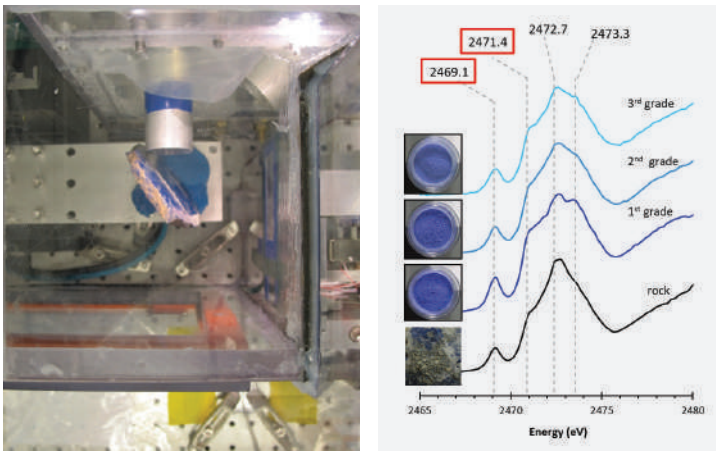
Recent Applications of Synchrotron Radiation for the Study of Historical Paintings

Emeline Pouyet and Monica Ganio
Northwestern University and the Getty Conservation Institute

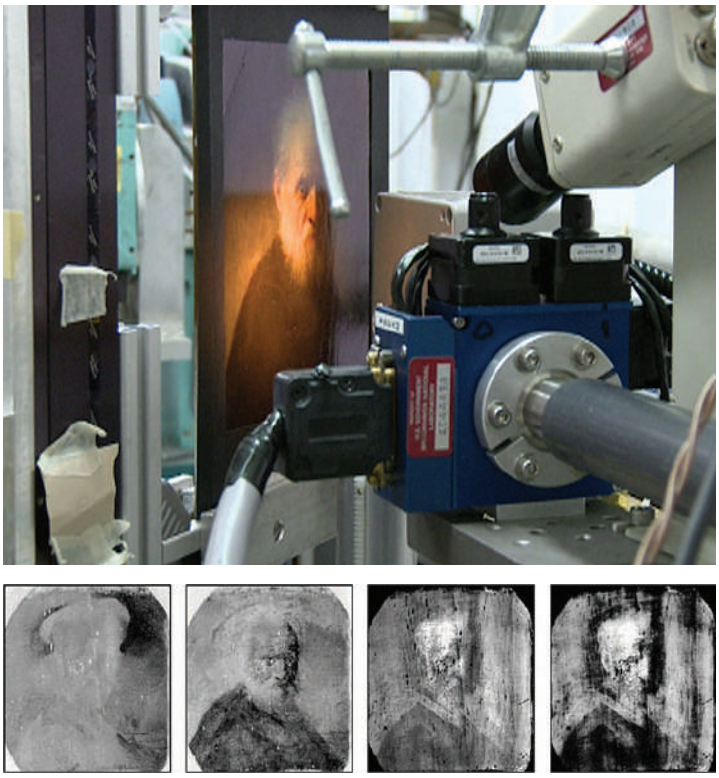
Synchrotron radiation (SR)-based techniques have become significant analytical tools in the field of cultural heritage (CH) over the last three decades[1-4]. Together with laboratory techniques, they help reveal information about the past and current history of a work of art[5]. On one hand, analyses are conducted to uncover ancient artistic manufacturing processes by rediscovering the nature of artists' materials and techniques (e.g., choice of resources, manufacturing processes, geographic provenance, trade routes). On the other hand, the goal may be to characterize and understand alteration phenomena and the effects of conservation treatments to improve restoration and conservation approaches.

Although encompassing a broad range of materials—such as ceramics and glasses, paintings, metals, papers, and wood-based objects—artworks share common specificities that motivate the use of a synchrotron source: complex chemical compositions, heterogeneities present at different length scales (from macro- to nano-), and sensitivity to radiation. Among the different types of cultural heritage objects, paintings represent one of the most challenging examples, being a heterogeneous, layered structure made of mixtures of organic and mineral, amorphous and crystallized, and major and minor components. In this context, the fundamental characteristics of the synchrotron source—high brightness, low divergence, highly linear polarization, and source tunability[1]—provide adapted spatial resolution (from a few mm to tens of nm), reduced acquisition time, and low detection limits (down to a few ppb). Chemical sensitivity and elemental speciation characterization address questions regarding extraction and purification processes of raw ingredients, heat treatments, chemical synthesis, and chemical reactivity. In particular, the energy tunability of the source allows spectroscopic analyses to be carried out over a wide energy domain, ranging from the infrared to hard X-ray regions. This provides the user access to a multi-modal platform of complementary analytical techniques, which is essential to understanding how the material complexity is related to chemical and physical processes inherent to the creation and degradation of a painting.

The use of non-invasive techniques—i.e., minimizing the need for sampling—has increased in the CH domain, in particular with the development of portable equipment for in situ characterization of painted materials[6]. In this context, SR large-area X-ray fluorescence spectroscopy (SR-XRF) has been successfully applied to elemental mapping of entire paintings[7,8]. The high incident flux and flux-density, combined with the use of a fast detector



Analysis of lapis lazuli and ultramarine blue pigments at the Stanford Synchrotron Radiation Lightsource, SLAC National Accelerator Laboratory, Menlo Park, Calif., USA. **Top:** the setup in use at beamline 14-3 for sulfur K-edge XANES. **Bottom:** the variation observed in the sulfur K-edge XANES following the 15th century purification process reported in literature by Cennino Cennini. ©JPGT

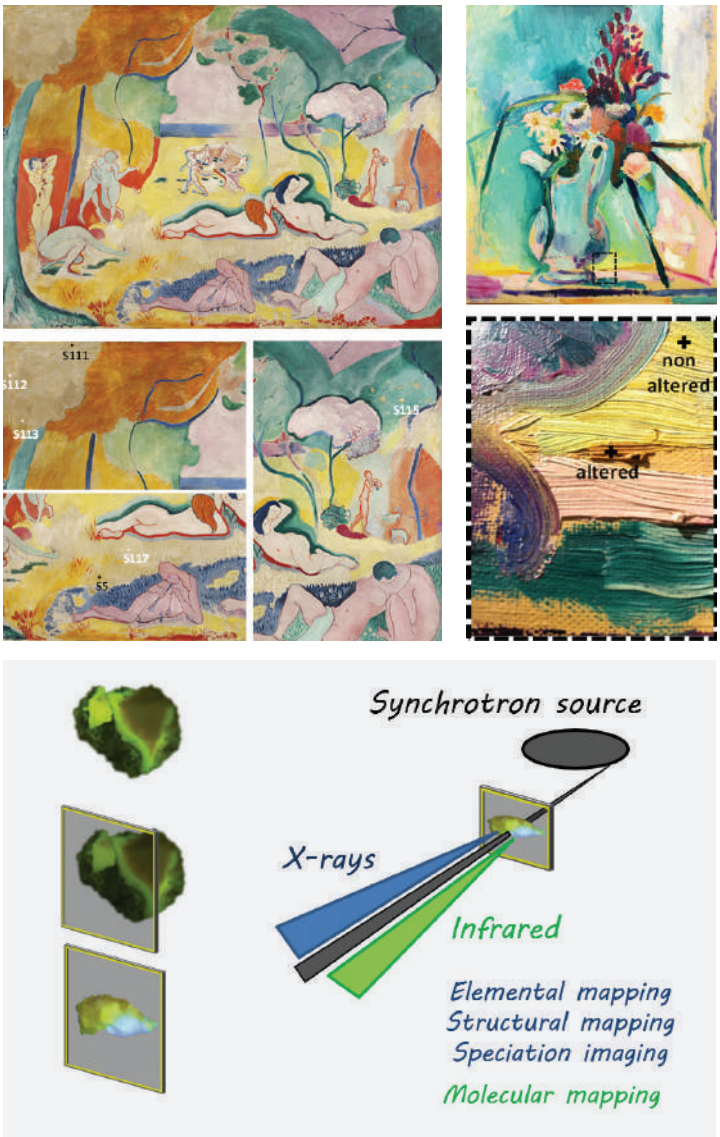


"Old Man with Beard", Rembrandt van Rijn, 18 x 17.5 cm, private collection; (c) R. Gerritse.. **Top:** the setup used for MAXRF scanning at the National Synchrotron Light Source, Brookhaven National Laboratory, Upton, N.Y., USA. **Bottom:** four of the elemental maps collected (Cu, Fe, Pb and Hg, respectively). The Cu distribution, in particular, reveals the outline of a man wearing a beret, possibly an unfinished self-portrait. Courtesy of Springer[20].

system, such as the Maia detector, result in higher density images obtained in less time than with most other macro-XRF scanner (MA-XRF) configurations[9]. As an example, this state-of-the-art set-up was recently applied to the technical study of The Blue Room (1901) by Pablo Picasso for mapping the elements specific to the pigments used in both the visible scene and hidden portrait underneath. These analyses increased the historical understanding of both pictures painted by Picasso and added to the growing body of knowledge about Picasso's early experimentation and evolving painting technique[10].

Moreover, the opportunities offered by SR large-area XRF scanning have been extended by its combined use with a large-area X-ray diffraction (XRD) system (Pilatus 300K area detector used in transmission mode), allowing elemental and crystalline phase mapping to be performed simultaneously at the object scale. Using this approach, trace-element and composition analyses of azurite pigments ($Cu_3(CO_3)_2(OH)_2$) in six illuminated manuscript leaves, dating from the 13th to 16th century, were performed, suggesting for the first time the possibility that azurite pigment impurities reflect distinct mineralogical and geologic sources and thus can be used for provenance studies[11].

However, the fact that SR large-area analysis cannot be performed on site (e.g., a museum, archeological field, etc.) is a major drawback that limits its application to a few cases, as it requires that the object travel to a large-scale facility—an opportunity not afforded to most objects, let alone entire collections. Thus, most of the SR-based analyses are usually performed on micro-fragments sampled from areas of interest. Paintings are very complex, multi-layered structures with heterogeneities at the micro- and nanometer scale; consequently, targeted micro-sampling is often necessary for in-depth probing of their stratigraphic structure. Cross sections are prepared to preserve the stratigraphy and allow microscopic observation of the components of individual layers as well as the relationship between layers. Thus, complementary chemically and spatially resolved techniques, combining spectroscopy and microscopy at the micro level are well suited to attain a full 2D, or even 3D, description of the composition of paint fragments. In this context, SR-based imaging techniques—in particular, micro Fourier transform infrared (μFTIR) and UV/visible spectroscopies, micro X-ray fluorescence (μXRF), micro X-ray absorption Near Edge Spectroscopy (μXANES) and micro X-ray Diffraction (μXRD)—have been increasingly used to reveal the painting's past and preserve their future[12]. For example, the advantage of this



Schematic representation of the sample preparation and multimodal platform used to analyze degraded CdS fragments from Henri Matisse The Joy of Life, oil on canvas (The Barnes Foundation, BF719, top left) and Flower Piece, 1906, (The Barnes Foundation, BF205, top right). Zoomed in areas of tan-brown alteration crusts and non-altered (yellow) regions of yellow paint are presented for each painting. Courtesy of Springer[13].

approach is demonstrated by recent studies of the degradation of cadmium-based yellow pigments[13,14]. This is a typical example in which the combination of μXRF, μXRD, μ- and full-field XANES, and μFTIR is crucial to understand the full chemical composition of the materials composing the altered painting. This approach confirmed previous hypotheses of the CdS pigment synthesis process (i.e., a reaction between CdCO3 and Na2S) and helped

determine that the degradation process responsible for the pigment whitening in some Impressionist paintings by Munch, Matisse and Van Gogh is based on the photo-oxidation of the yellow CdS pigment to white $CdCO_3$ crystals.

Although the examination of the microstructure of paint samples is a well-established procedure, pushing the spatial resolution to the nanoscale is still limited to a few examples. Nanoprobe XRF has been recently used to map and localize impurities within sub-micrometric zinc white pigment particles used in early 20th century tube paints and enamel paints, with particular emphasis on Ripolin, a popular brand of French house paint. The presence of different impurities offered a tool for distinguishing different manufacturing strategies and provided an increased understanding of their chemical reactivity and luminescence properties[15]. Another recent study of samples from 16th to 19th century French and Flemish blanched paintings used magnified phase contrast imaging to determine the size, morphology and spatial distribution of the pores (typically about 200 nm to 4 μm) within paint varnishes responsible for the whitening of the paint layers. By comparing both restored and original samples, the results suggested that the restoration treatment was not filling or reducing any of the pores present in the varnish layer. This data provided the basis for evaluating the efficacy of new conservation strategies[16].

With the increasing application of micro- or nano-focused beams to the study of paint material for speciation, characterization, provenance, and degradation studies, the associated risk of radiation damage has become a subject of discussion in conservation communities[17]. Although these questions are just emerging, a few studies are already tackling the issue of radiation damage on photo-sensitive pigments such as Prussian blue[18] or ultramarine[19]. They showed that by determining and adjusting dose ratios relevant analysis results can be obtained without damaging the object. Moreover, by characterizing the ionization effect of photo-sensitive materials, parallels can be proposed with current degradation mechanisms, extending 3D analysis to 4D analyses where kinetic reactions are being investigated.

Picture of the two authors at the Stanford Synchrotron Radiation Lightsource, SLAC National Accelerator Laboratory, Menlo Park, Calif., USA. On the left, the setup in use at beamline 14-3.

The application of SR-based techniques goes far beyond the few examples reported here. The development of experimental stations devoted to the study of CH, such as IPANEMA (SOLEIL, France) ID-21 (ESRF, France), and the increased number of proposals addressing archaeology and art history related questions, is surely destined to push for further dedicated synchrotron measurements and methodological developments.

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Summaries by the Winners of IPAC17 Student Poster Awards

Congratulations to the two winners of the Student Poster Awards at IPAC 2017, Daniel Hall and Annalisa Romano! Below are summaries that the students have written for the general community describing their work.

Macroparticle Simulation Studies of the LHC Beam Dynamics in the Presence of Electron Cloud

Annalisa Romano,
Technische Universität Darmstadt and CERN

In high energy accelerators operating with positively charged particles, photoemission and secondary emissions can give rise to an exponential electron multiplication within the beam chamber, which leads to the formation of a so-called electron cloud (EC). Beam quality degradation caused by the EC effects has been identified as one of the main performance limitations for the high-intensity 25 ns beams in the CERN Large Hadron Collider (LHC).

When a proton bunch passes through an EC, electrons are attracted towards the transverse center of the beam resulting in an increasing electron density within the bunch. Effects caused by the interaction of the electrons with the bunch have been investigated through macroparticle simulations. These studies were aimed at explaining the underlying mechanism of EC observations during the 2015-2016 proton run. In particular, the observed instabilities at injection and collision, as well as beam losses were addressed by assessing the threshold for the coherent instability and studying the incoherent tune spread generated by the EC. Simulation results showed that the presence of EC in the LHC quadrupoles alone can drive the beam unstable at injection, in both in the horizontal and the vertical planes.

In order to preserve the beam stability, large chromaticity values and relatively high octupole currents are needed together with a fully functional transverse feedback. However, simulations showed that the tune spread generated by the EC and high chromaticity can lead to a quite large tune footprint that reaches the third-order resonance. This explained the observed beam lifetime degradation. Based on these results, the optimal settings for the LHC fractional tunes have been found and used in operation for the 2016-2017 run.

Impact of Trapped Magnetic Flux and Thermal Gradients on the Performance of Nb_3Sn Cavities

Daniel Hall,
Cornell University

Nb_3Sn is a promising alternative to niobium in the construction of superconducting cavities used for high-repetition-rate particle accelerators, such as the European XFEL and the upcoming LCLS-II light sources. A major cost driver in these applications is the efficiency of the cryogenic plant necessary to keep the cavities superconducting. Nb_3Sn promises to reduce the power draw from the grid by up to 80 percent compared to the current state of the art, resulting in a significant reduction in operating cost over the lifetime of the machine.

In order to achieve this improvement in efficiency, it is crucial to minimize the amount of magnetic flux trapped in the superconductor during the cooldown through the superconducting transition. This work focuses on identifying sources of trapped flux and quantifying the impact of such on the efficiency of the cavity as a function of the operating gradient, placing constraints on the operational parameters for the desired machine performance. We demonstrate that the desired high efficiency can be repeatedly achieved in proof-of-principle R&D, and that the technology is ready for a fully functional prototype.

Student Poster Award winners at IPAC 2017,
Annalisa Romano (middle right) and Daniel Hall (middle left).

APS DPB
Awards & Fellowships

Robert R. Wilson Prize for Achievement in the Physics of Particle Accelerators, 2017

Anton Piwinski,
DESY
Citation: "For the detailed, theoretical description of intrabeam scattering, which has empowered major discoveries in a broad range of disciplines by a wide variety of accelerators, including hadron colliders, damping rings/linear colliders, and low emittance synchrotron light sources."

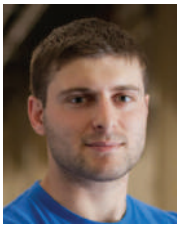
James Bjorken
SLAC - National Accelerator Laboratory
Citation: "For the detailed, theoretical description of intrabeam scattering, which has empowered major discoveries in a broad range of disciplines by a wide variety of accelerators, including hadron colliders, damping rings/linear colliders, and low emittance synchrotron light sources."

Sekazi Mtingwa
Massachusetts Institute of Technology
Citation: "For the detailed, theoretical description of intrabeam scattering, which has empowered major discoveries in a broad range of disciplines by a wide variety of accelerators, including hadron colliders, damping rings/linear colliders, and low emittance synchrotron light sources."

Outstanding Doctoral Thesis Research in Beam Physics Award, 2016

Panagiotis Baxevanis
SLAC - National Accelerator Laboratory
Citation: "In recognition of outstanding contributions to the theory of three dimensional effects in free electron lasers."

Outstanding Doctoral Thesis Research in Beam Physics Award, 2017



Spencer J. Gessner
SLAC - National Accelerator Laboratory
Citation: "In recognition of an original theoretical treatment and an experimental demonstration of accelerating positrons in a hollow channel plasma wakefield accelerator."

APS Fellow Nominations by the DPB in 2017

John Galambos,
Oak Ridge National Laboratory
Citation: For outstanding leadership and vision in the design, commissioning, and effective operation of high power hadron accelerators.

Andrew Hutton,
Jefferson Lab
Citation: For extensive technical contributions to accelerators world-wide as designer and adviser; for leading the commissioning and operation of world's first large scale superconducting radio frequency accelerator at Jefferson Lab; and for fostering graduate education in accelerator science and technology.

Michiko G. Minty,
Brookhaven National Laboratory
Citation: For achievements in beam instrumentation and operations leading to greatly enhanced performance of the Relativistic Heavy Ion Collider.

Pietro Musumeci,
University of California, Los Angeles
Citation: For pioneering work in the physics of high brightness beams, including ultrafast relativistic electron diffraction, and high gradient inverse free electron laser acceleration.

Evgenya Smirnova-Simakov,
Los Alamos National Laboratory
Citation: For the development of photonic-band gap accelerating structures.

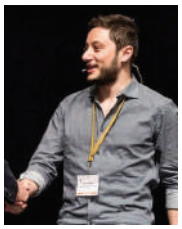
Steier, Christoph
Lawrence Berkeley National Laboratory
Citation: For seminal contributions to the understanding, development, and operation of storage ring based synchrotron light sources, including effects of intrabeam scattering, lattice optimization, undulator compensation, and brightness improvements.

International Particle Accelerator Conference Prizes, 2017

The Rolf Wideröe Prize for "outstanding work in the accelerator field without age limit" is awarded to Dr. Lyndon Evans of CERN. For his major professional accomplishments in the field of accelerator design, construction and operation, including his contributions to the SPS, where he was essential for converting the SPS to a proton-anti-proton collider that led to the discovery of the W and Z Bosons, and the design and construction of the LHC, which led to the discovery of the Higgs Boson in 2012.

The Gersh Budker Prize, for "a recent significant, original contribution to the accelerator field, with no age limit," is awarded to Dr. Pantaleo Raimondi of ESRF. For the invention of the Hybrid Multi Bend Achromat HMBA-lattice for the upgrade of the ESRF Synchrotron Light Source, aiming at reducing the emittance by a factor of 30 while still fulfilling the constraint to keep the original beam lines structure.

The Frank Sacherer Prize, for "an individual in the early part of his or her career, having made a recent significant, original contribution to the accelerator field," is awarded to Dr. Anna Grassellino of Fermilab. For her major impact on the field of superconducting RF technology, in particular, the improvement of the cavity quality factor Q and more recently the accelerating field gradient and quality factor combined.



The Bruno Touschek Prize winner, awarded to a student registered for a PhD or diploma in accelerator physics or engineering or to a trainee accelerator physicist or engineer in the educational phase of their professional career, for the quality of work and promise for the future, was awarded to Fabrizio Guiseppe Bisesto of INFN/LNF. For his contributions to the plasma related activities underway at SPARC_LAB exploiting the high-power laser FLAME.

An Interview with Spencer Gessner: DPB Dissertation Award Recipient

Spencer Gessner
CERN

1) 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?

In plasma accelerator research, we try to accelerate electrons and positrons to very high energies using plasma as the accelerating medium. The acceleration process for traditional accelerators is charge agnostic—the RF cavities accelerate electrons and positrons the same way, just 180 degrees out of phase. On the other hand, a plasma responds asymmetrically to electron and positron beams. This is because the plasma is composed of light, mobile electrons and heavy, immobile ions. The hollow channel plasma is an attempt to recover the charge-symmetric response of traditional RF cavities in a plasma-based accelerator. We create a tube of plasma in which there is no charge on axis, and the accelerating fields are generated by the motion of plasma electrons in the channel walls. In my thesis work, we were able to create this plasma structure and demonstrate that it can be used to accelerate positrons.

The concept of the hollow-channel-plasma accelerator was first proposed over 20 years ago, and at the time, many physicists saw it as a pipe dream. I think the main impact of my research was to demonstrate that we can create this type of ephemeral plasma structure and use it to accelerate particle beams before the plasma structure disappears. The hollow channel plasma is a useful geometry for accelerating positrons, but there might be many other shapes we can create that optimize certain aspects of the acceleration process.

2) How did you get into the field of accelerator physics and your research area, in particular?

As an undergraduate, I did research on the CMS detector at the LHC, and in the summer before I started grad school at Stanford, I worked with the SLAC ATLAS group at CERN. I really loved these research experiences, but I was also interested in the future of particle physics after the LHC. It was around this time that I became aware of the FACET project at SLAC. FACET was the only facility in the world capable of providing electron and positron beams for plasma wakefield acceleration (PWFA) research. As a student interested in the future of high energy physics, FACET seemed like a great opportunity to start answering the question: What comes next?

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

Dealing with technical and conceptual challenges is part of the job of being a graduate student and a scientist, so I didn't really focus on these issues as obstacles to my research. The main obstacle I encountered was my ability (or inability) to manage my own time. Time mismanagement is a problem because laboratory research is often unstructured. I like to work in spurts, and that was OK for certain parts of my project, but when it came time to write my thesis, I needed to make steady progress. I constantly felt guilty because I was chapters behind where I needed to be, and I ended up taking an extra term to finish.

4) What advice do you have for current graduate students in accelerator physics?

My first piece of advice is to choose a research topic that you enjoy and find intellectually stimulating. It's tempting to measure the success of your graduate career in terms of publications or scientific accomplishments, but there are considerable outside factors that affect the progress of student research projects. Funding may come and go, beam time can be scarce, and you have to manage your own life in a new environment. But if you like your work, you will more easily overcome the frustrations that are inherent to physics research.

My second piece of advice is to choose the people you work with. At Stanford, we were encouraged to do "research rotations," in which we worked in different labs over the course of our first year. This was a great opportunity, and I was exposed to a lot of interesting research. When I rotated into Mark Hogan's FACET group, I realized that I had hit the jackpot because I was excited about plasma wakefield acceleration, and Mark had put together a great team. The scientists I met working on FACET ended up becoming my friends, and it's a good thing we got along because we had to spend many long nights in the control room working on the experiment.

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

I now work on the AWAKE project at CERN. AWAKE is the first proton-beam-driven PWFA experiment. The goal of the experiment is to use the 400 GeV proton beam from the Super

Proton Synchrotron to accelerate a trailing electron beam. This is related to my research at FACET since I use many of the same concepts and techniques, but the AWAKE experiment breaks new ground in a number of ways. The size and scale of the experiment are an order of magnitude beyond anything done so far in PWFA research. The plasma cell at AWAKE is 10 meters long, and we are already investigating ways to extend it to 100 meters long. At that size, it may be possible to accelerate electron beams in a single pass to energies that are interesting for high energy physics experiments.

6) Any plans or aspirations for the future? Where do you see the future of plasma wakefield acceleration heading?

There are number of PWFA research facilities coming online in the near term, including FLASHForward at DESY, FACET-II at SLAC, and AWAKE Run II at CERN. At the same time, rapid progress is being made in Laser Wakefield Acceleration at laboratories across the world. It's exciting to see all these experiments running because there are many challenges that need to be addressed in order to transition plasma wakefield accelerator research into plasma wakefield accelerator technology.

As a career aspiration, I hope to someday be involved in building a plasma-based linear collider (PLC). There are new efforts in the U.S. and Europe to create a roadmap towards a high-energy PLC. The goal of the roadmap is to point out obstacles on the way to a PLC and identify the experiments needed to address these issues. I suspect that my research will focus on finding novel solutions to challenges in plasma wakefield acceleration for the foreseeable future.

7) Tell us a fun fact about you! An interesting hobby, perhaps?

CERN is in the French-speaking part of Switzerland, so my main hobby at the moment is learning to speak French. Last December, just a few months after I arrived, I was really struggling with the language. I had to go into the accelerator tunnel to check on the AWAKE plasma cell, which we were heating for the first time. I smelled something funny, so I called the technician, but he didn't speak English. I tried to explain the issue, but I wasn't getting through. Then, I saw smoke coming from one end of the plasma heater. "TROP CHAUD! TROP CHAUD!" ("TOO HOT!") I yelled. The technician understood and turned off the heater.

So my third piece of advice is that if you really want to learn a foreign language, put yourself in life-or-death situations.

Spencer Gessner, recipient of the 2017 DPB Dissertation Award, at the FACET beamline.

University Spotlight: UCLA Particle Beam Physics Laboratory

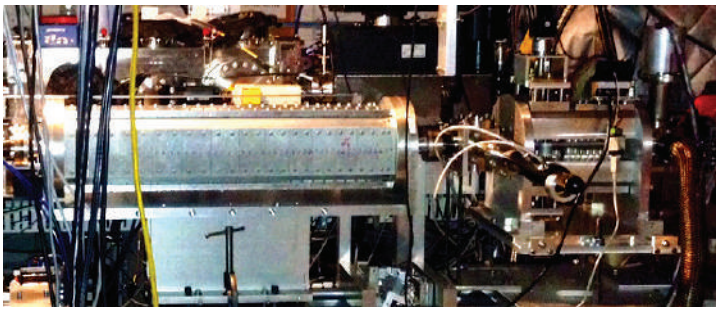
James Rosenzweig
University of California Los Angeles

The decidedly university-flavored research team at the UCLA Particle Beam Physics Laboratory (PBPL) stirs a bit late, with a dedicated few arriving by 9 a.m. The science done at the PBPL is performed more at nocturnal times and often in other time zones. By mid-morning, the lab offices come to life, populated by over a dozen graduate students, undergraduate assistants, post-docs, professional researchers, and engineers. The two faculty round out the lab mix, Professors James Rosenzweig and Pietro Musumeci. The PBPL fills an extended nucleus of offices in UCLA's Knudsen Hall.

This particular Monday, the team will be near full strength, with a half-dozen members coming back from conference travel to the European Advanced Accelerator Conference in Italy and the Accelerator on a Chip (ACHIP) collaboration meeting. There they reported results on a range of interconnected fields: GV/m field dielectric wakefield accelerators; novel plasma wakefield acceleration and lensing techniques; use of THz radiation for beam manipulations; inverse free-electron lasers; dielectric inverse Compton scattering light sources; and next-generation, high-brightness electron sources from plasmas and ultra-high-field RF structures. This selection represents the three-pronged research emphasis of the PBPL: investigating 1) advanced accelerators based on lasers, beams and plasmas; 2) new generations of light sources such as the free-electron laser; 3) the fundamental beam physics and technology that underpins these fields. The students who undertake the lion's share of the work in the PBPL take ownership over important components of these fields. As such, in addition to authoring journal publications, students represent the lab in major conferences, shouldering the responsibility for talks and posters.

By the time a PBPL student receives their Ph.D. from UCLA, they are well integrated into the international research community, not only through conferences, but through collaboration. While the core of PBPL research takes place in unique, on-campus photoinjector labs, to accomplish all the goals of the program, it is necessary to move some experiments off-campus to national lab facilities. The PBPL has programs in two user accelerator facilities maintained by the U.S. Department of Energy: the Brookhaven (BNL) Accelerator Test Facility (ATF), and the FACET Wakefield Acceleration lab at SLAC. The PBPL team has strong collaborations with both facilities, influencing the direction of their science programs and the development of their experimental infrastructure—contributing RF and magnetic devices, and sub-femtosecond beam diagnostics. At the ATF, a string of frontier experiments on plasma and dielectric wakefields have culminated recently with a study of wake-excited photonic structures that lead to a Ph.D. for student Phuc Hoang.

Other PBPL experiments at BNL are concentrated on what is termed the 5th generation light source—a new way of producing bright, ultrafast beam-based radiation using an advanced accelerator to create a compact light source. This PBPL project joins expertise in inverse Compton scattering (ICS) with inverse free-electron lasers (IFEL) to produce X-rays in periodic bursts separated by 30 femtoseconds. This experiment has produced a number of publications as well as the Ph.Ds. of students Joe Duris, Ivan Gadjev, and Nick Sudar. Many of the recent doctoral theses at BNL were supported by fellowships from DOE's Science Graduate Student Research program, which is dedicated to giving access to national lab facilities for Ph.D. work.



UCLA RUBICON advanced IFEL experiment at the BNL Accelerator Test Facility.

PBPL work at the ATF is complemented by the unique capabilities and collaborations established at the SLAC FACET facility. FACET is the premier lab for creating intense beams needed to access >GV/m fields in wakefield acceleration. The work in dielectric wakefield acceleration (DWA) recently demonstrated several-GeV/m acceleration and revealed fundamental nonlinear effects in very high field waves in solids. This work led to the Ph.D. of student Brendan O'Shea. On the side of plasma wakefield acceleration (PWFA), UCLA PBPL contributed to the first demonstration of a "plasma photocathode," in which high-brightness electron beams are directly photo-excited inside a multi-GV/m amplitude plasma wave. This complex, experimental work (see Figure 2) was led at SLAC

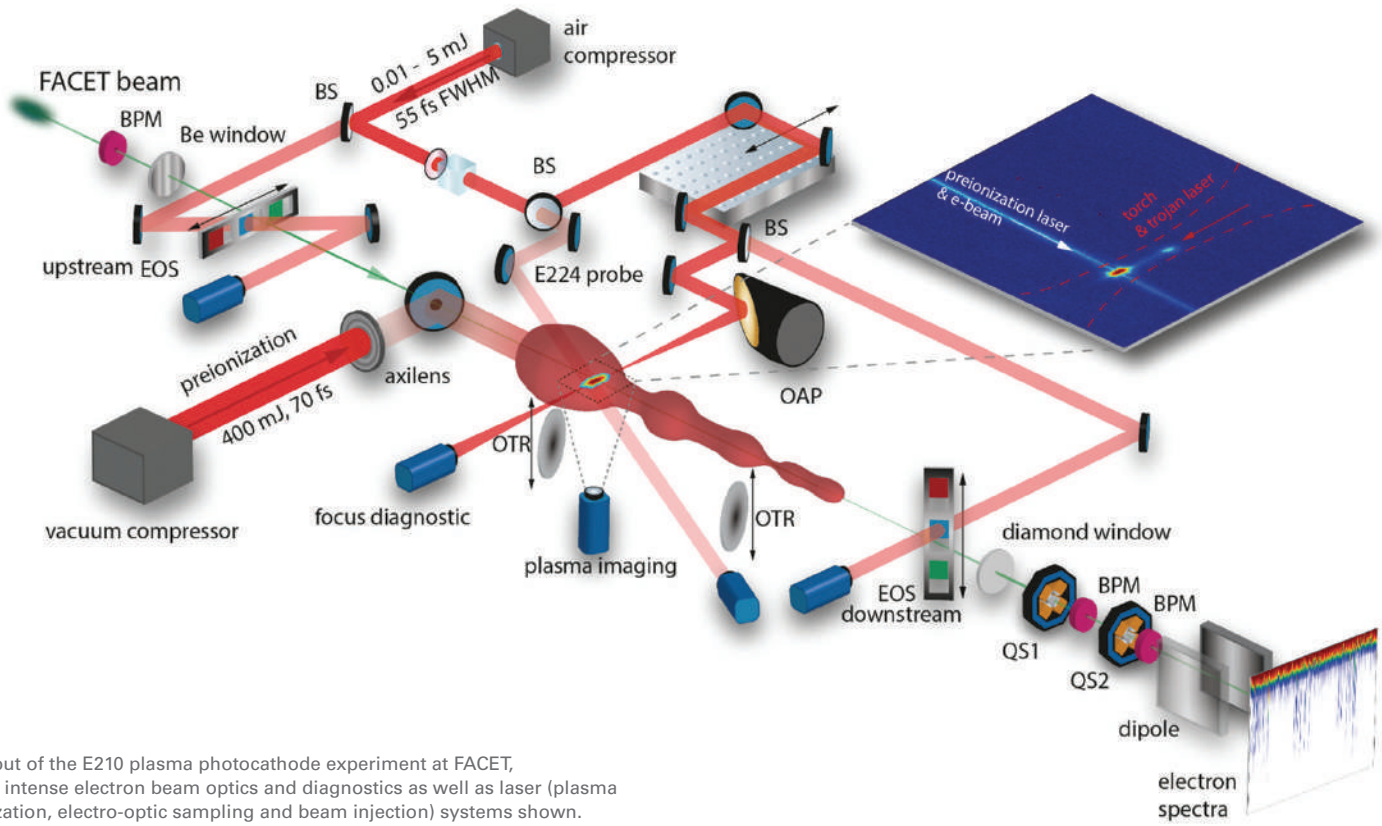
by UCLA post-doc Aihua Deng and produced the Ph.D. of student Yunfeng Xi. The project involved a wide collaboration including the University of Hamburg, Stanford University, and the University of Strathclyde.

The student names mentioned above point to a notable trend: the existence of a student pipeline from UCLA to SLAC, a worldwide center of activity in free-electron lasers, high-field accelerators and electron sources, and wakefield acceleration. SLAC currently employs eight recent PBPL Ph.Ds. working on FACET, LCLS X-ray FEL, and beyond. In this group are two recipients of the lab-wide Panofsky Fellowship, and two winners of the International Young FEL Scientist Prize.

With FACET II still awaiting construction, the PBPL is actively involved in planning for its scientific program. New initiatives that exploit the potential of PWFA to create TV/m fields—important for both plasma acceleration and basic atomic physics—and ultra-strong undulating fields for advanced light sources are being developed for this next-generation facility. There is also a burgeoning collaboration on a PWFA experiment at the Argonne (ANL) Wakefield Acceleration facility that aims to enhance the efficiency of wakefield schemes. In another direction, joint work is under way on a laser-plasma-accelerator-driven free-electron laser with the BELLA group at Lawrence Berkeley National Laboratory, a development funded by the Moore Foundation. UCLA is providing the 4-m long VISA undulator, magnetic optics, and light diagnostics in this experiment.

In recent years, the PBPL has joined several large research consortia, with support coming from the NSF in the form of two Science and Technology Centers (the Center for Bright Beams, and the advanced imaging initiative called STROBE), the Moore Foundation (BELLA FEL and ACHIP), and the Keck Foundation (Micro-undulator FEL@UCLA). Between these activities and existing core missions, PBPL collaborators includes: INFN-Frascati; University of Erlangen; University of Bern; Tel Aviv University; Cornell University; University of Chicago; and the U.S.

(continued on back page)



Layout of the E210 plasma photocathode experiment at FACET, with intense electron beam optics and diagnostics as well as laser (plasma ionization, electro-optic sampling and beam injection) systems shown.

Meet the 2017 Executive Committee

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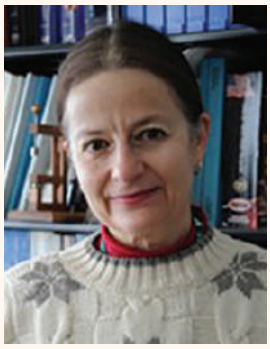

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Upcoming Meetings

Date	Title	Location
January 15 - 25, 2018	U.S. Particles Accelerator School (USPAS)	Hampton, United States
February 6 - 9, 2018	TESLA Technology Collaboration (TTC) Meeting	Milano, Italy
February 21 - March 6, 2018	CERN Accelerator School: Beam Dynamics and Technologies for Future Colliders	Zurich, Switzerland
March 4 - 9, 2018	ICFA Advanced Beam Dynamics Workshop on Future Light Sources (FLS '18)	Shanghai, China
March 5 - 9, 2018	APS March Meeting 2018	Los Angeles, United States
April 8 – 13, 2018	Meeting of the Future Circular Collider Study (FCC Week 2018)	Amsterdam, Netherlands
April 14 - 17, 2018	APS April Meeting 2018	Columbus, United States
April 29 - May 4, 2018	International Particle Accelerator Conference (IPAC '18)	Vancouver, Canada
June 2 - 15, 2018	CERN Accelerator School: Beam Instrumentation	Tuusula, Finland
June 11 - 16, 2018	International Conference on Synchrotron Radiation Instrumentation (SRI '18)	Taipei, Taiwan
June 17 – 22, 2018	ICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams, (HB2018)	Daejeon, Korea
June 25 - 29, 2018	Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation (MEDSI '18)	Paris, France
August 12 - 17, 2018	Advanced Accelerator Concepts Workshop (AAC18)	Breckenridge, United States
August 12 - 17, 2018	International Conference on Application of Accelerators in Research and Industry (CAARI 2018)	Grapevine, United States
September 17 - 21, 2018	International Beam Instrumentation Conference (IBIC '18)	Shanghai, China
September 17 -21, 2018	Linear Accelerator Conference (LINAC '18)	Beijing, China
May 19 - 24, 2019	International Particle Accelerator Conference (IPAC '19)	Melbourne, Australia
August 25 - 30, 2019	International Free-Electron Laser Conference (FEL '19)	Hamburg, Germany
September 22 - 27, 2019	North American Particle Accelerator Conference (NA-PAC 2019)	Lansing, United States
October 5 - 11, 2019	International Conference on Accelerator and Large Experimental Physics Control Systems (ICALEPCS '19)	New York, United States

In Memoriam

Larry Phillips

Charles Reece, Jefferson National Accelerator Laboratory

The accelerator community mourns the passing of Dr. Larry Phillips (H. Lawrence Phillips), who has held a Senior Accelerator Physicist position at Jefferson Lab since 1986. He passed away on Sept. 30, 2017.

The principle strength that Larry brought to his work at JLab was that he considered technical application material challenges (which are rather common in the development of accelerator technology) to be merely physics puzzles that had many different viable solutions. "Just analyze the physics and then tailor the solution, easy" – he would say. He was cut from the general experimental physicist cloth that welcomes with optimism new puzzles as fresh opportunities to develop improved understandings that could then be brought to bear in creative, targeted solutions.

After undergraduate training in physics at Rutgers, Larry worked for Sperry in the electronic vacuum tube industry then earned his Ph.D. at Stevens Institute of Technology under Prof. Hans Meissner. After a postdoc appointment at the University of Karlsruhe, in 1972 Larry accepted a position at Cornell University in the accelerator development team lead by Maury Tigner. He was responsible for finding very cost-effective and novel solutions for the integrated beamline and vacuum system of the CESR electron storage ring.

Once CESR was in operation, the team turned its attention to the development of a superconducting RF cavity system that was to be the basis of a large collider proposed for construction at Cornell. Although the high energy physics research went to the SLC at SLAC, the 5-cell niobium cavities developed and tested for that project were later adopted for use in CEBAF. Larry compiled the reference documentation that was used to transfer the technology to fabricate those cavities to industry. He was the first member of the SRF team to relocate to Virginia to build CEBAF.

Larry was also responsible for the ceramic waveguide windows that couple rf power from each klystron into the beamline vacuum envelope. He conceived and co-invented a novel superconducting rf pickup probe that ensures beam stability in CEBAF and was adapted for use throughout the European XFEL and LCLS-II. Always happy to be a problem-solver, Larry regularly contributed sound physical insight to the untangling of perplexing phenomena brought to his attention by colleagues throughout the JLab community.

Numerous more junior staff credit him with coaching them through solutions to problems in cryogenics, vacuum, RF, brazing, electron beam welding, cleaning, and novel materials circumstances. Most recently, Larry was investing his attention into the development of high-performance thin film superconducting materials that many believe will eventually supplant the use of bulk niobium in accelerator applications.

Larry served as advisor to 10 different Ph.D. projects undertaken in SRF at JLab. Just this past March these students organized a retrospective appreciative event at the lab on the occasion of his 80th birthday. We will miss his wealth of experience, physical insight, and never-ending optimism.

Satoshi Ozaki

Karen McNulty Walsh, Brookhaven National Laboratory

Satoshi Ozaki, a world-renowned physicist who helped design and build accelerators for scientific research across two continents, including two of the flagship facilities at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory, died on July 22, 2017, at the age of 88. He was a Senior Scientist Emeritus at Brookhaven Lab and a key driver of international collaborations in high-energy and nuclear physics.

"From his first days at Brookhaven, Satoshi had a tremendous impact on Brookhaven's science," said Brookhaven Lab Director Doon Gibbs. "He was one of the world's foremost accelerator builders. His contributions to Brookhaven Lab were numerous, wide-ranging, and always characterized by his wisdom. The success of the Relativistic Heavy Ion Collider (RHIC) stands as a monument to his leadership, but he also left an indelible mark on the National Synchrotron Light Source II (NSLS-II). He was a wonderful mentor to many at Brookhaven and beyond, and he was a true friend."

High-energy physics and detector development

Ozaki joined Brookhaven Lab in 1959 with a master's degree in physics from Osaka University, Japan, and a Ph.D. in physics from the Massachusetts Institute of Technology. He worked in a group he eventually co-led with Samuel Lindenbaum on experiments at Brookhaven's Alternating Gradient Synchrotron (AGS), developing state-of-the-art electronic detectors and an online data

facility for monitoring detector performance by reconstructing subsets of data in real time. This was the first system of its kind and is now a routine component of data acquisition systems for complex electronic detectors. The Ozaki-Lindenbaum group also developed a multiparticle spectrometer at the AGS that served many experimental groups at Brookhaven and collaborating universities. In addition, Ozaki led the development of detectors for ISABELLE, the first design for a dual-ring superconducting collider at Brookhaven.

Ozaki's work in experimental particle physics and large scale detector development at Brookhaven led to a 1981 invitation from the National Laboratory for High Energy Physics, KEK, in Japan to direct the construction of TRISTAN, the first major high-energy particle collider in that country. Under Ozaki, this $500-million project was completed on time and within budget to start operations in 1987, accelerating and storing beams of electrons and positrons at 30 billion electron volts—the highest energy in the world at the time. Since 1978, Ozaki was also involved in the initiation and oversight of an Agreement on High Energy Physics between the Japanese and U.S. governments. This highly fruitful program fostered relationships among scientists in the two nations and laid the groundwork for large-scale collaborative projects.

The Birth of RHIC

In 1989, Ozaki returned to Brookhaven Lab to head the Relativistic Heavy Ion Collider (RHIC) project.

"It was a pleasure to welcome Satoshi and his wife, Yoko, back to Brookhaven National Laboratory. The timing was auspicious, the construction of TRISTAN was successfully completed and RHIC was ready to be launched," said Nicholas Samios, director of the Laboratory at the time. "Satoshi was the right man, at the right place, at the right time to head the RHIC construction project, which he admirably accomplished."

RHIC is a 2.4-mile-circumference collider that researchers use to smash atomic particles together to study the building blocks of visible matter and the fundamental force that holds them together to create atoms, stars, planets and everything we see in the universe today. Under Ozaki's leadership the RHIC project was successfully completed, with first collisions in 2000, driving experiments with a complement of four advanced particle detectors operated by international collaborations consisting of many hundreds of scientists. RHIC is currently the highest energy colliding beams facility in the U.S., and has made many important discoveries about an extreme state of matter known as quark-gluon plasma and the origin of proton spin.

Ozaki was essential in securing Japanese support for RHIC-related projects, including key accelerator components to allow collisions of spin-polarized protons at RHIC as well as major components of the PHENIX detector. He played a central role in establishing the partnership between RIKEN—Japan's Institute of Physical and Chemical Research—and Brookhaven to establish the RIKEN BNL Research Center (RBRC). He served as the senior member of RBRC's six-person Management Steering Committee. RBRC physicists, who come from RIKEN, Brookhaven Lab, and many other institutions around the world, have worked together since 1997 to understand and explore in depth the results from particle collisions at RHIC.

A Bright New Light

In 2005, Ozaki joined the National Synchrotron Light Source II (NSLS-II) project to lead construction of this world-leading facility at Brookhaven Lab. NSLS-II accelerates electrons and delivers synchrotron radiation emitted by these particles in the form of extremely bright, intense beams of x-ray, ultraviolet, and infrared light. Scientists use these beams to reveal unprecedented details about materials ranging from batteries to solar cells, catalysts, and proteins. As the initial head of the NSLS-II Accelerator Division, Ozaki built up the group, attracting staff and leading development for the accelerator portion of the facility's conceptual design. He remained with the project as a senior advisor even after formally retiring on December 31, 2012, taking on a major task of procuring the storage ring magnets, and attended the formal dedication of the completed facility in February 2015.

Ozaki also chaired the Accelerator System Advisory Committee for the Facility for Rare Isotope Beams (FRIB) currently under construction at Michigan State University. FRIB will produce rare isotopes created in the cosmos so scientists can study their decay to better understand the origins of the elements found on Earth.

Ozaki's accomplishments have been recognized with numerous prestigious awards. Among them are the 2007 IEEE Nuclear and Plasma Sciences Society Accelerator Science and Technology Award, which he shared with Michael Harrison for leadership in the successful design and construction of RHIC. He also received the 2009 Robert R. Wilson Prize of the American Physical Society for his contributions to accelerator science and technology on two continents and his promotion of international collaboration. In 2012, he received a commendation from the Consul General of Japan, which was followed in 2013 with Japan's prestigious Order of the Sacred Treasure, Gold Rays with Neck Ribbon, conferred by Emperor Akihito of Japan—both recognizing Ozaki's outstanding contributions in physics through high-energy and nuclear physics studies, as well as his significant contributions to the promotion of Japan-U.S. cooperation in physics. In 2016, he received a BSA Distinguished Service Award from Brookhaven Science Associates (BSA), the company that manages Brookhaven Lab for DOE's Office of Science, in recognition of his lasting, impactful, and substantial contributions to the Laboratory and DOE since joining Brookhaven Lab.

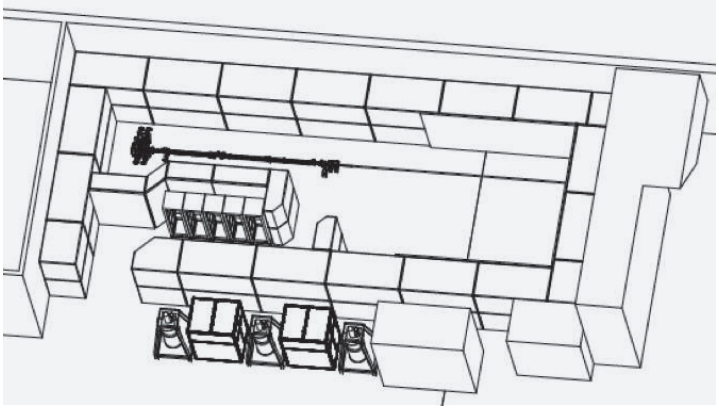
Ozaki was pre-deceased by his wife, Yoko, and is survived by their two children, Keiko Simon and Tsuyoshi Ozaki, their spouses, and four grandchildren.

(continued from page 31) national labs ANL, BNL, LBNL, Los Alamos National Laboratory (LANL), Fermi National Accelerator Laboratory (FNAL), and SLAC. These relationships are augmented by industrial collaborations, particularly with the UCLA spin-off company RadiaBeam Technologies, a leader in accelerator technology.

While PBPL students, post-docs and researchers travel frequently for these collaborations, UCLA also hosts visitors who work at laboratory facilities on campus, including two photoinjector-based labs: Pegasus and SAMURAI. Pegasus, operated under the direction of Prof. Musumeci, is a lower energy lab (~3-12 MeV) that concentrates on production and application of beams having extremely low emittances. Pegasus is a leader in the emerging fields of ultra-relativistic electron diffraction (UED) and microscopy (UEM), and performs advanced studies on photocathode physics. Pegasus also hosts work on the use of THz radiation in accelerators and beam diagnostics, which has emerged as a focus of the ACHIP collaboration with dielectric laser acceleration at the GV/m-level shown.

SAMURAI Lab is under construction at the UCLA Science and Technology Research Building (STRB). It is directed by Prof. Rosenzweig and continues programs initiated in the Neptune Laboratory. SAMURAI Lab combines a TW laser with a hybrid photoinjector that can produce sub-picosecond beams at high charge. The project has an ambitious agenda beginning with development of new, short-wavelength FELs using micro-undulators, which started as a Keck-supported project. As part of this advanced FEL program, UCLA is developing a new approach to photoinjectors based on extremely high-field cryogenic copper techniques, now being examined for the next-generation X-ray FEL at LANL, as well as novel approaches to high harmonic generation and seeding. It will also be home to development of a high-flux ICS source aimed at advances in monochromatic X-ray-based cancer therapy. Finally, this high-intensity beam source, which is placed at the UCLA STRB with leading large-volume plasma devices, should find application in plasma wakefield studies that impact not only new accelerators, but also space plasma physics.

With all this activity, the UCLA PBPL will be a productive beehive of accelerator science in the coming years, carrying on a 25-year tradition. Given the scope of the program, the team may soon have to attack the research before 10 a.m.



Schematic cutaway view of initial 65 MeV operating layout of SAMURAI advanced injector and FEL lab at UCLA Science and Technology Research Building, now under construction.

APS Locations

Headquarters
1 Physics Ellipse
College Park, MD 20740-3844
(301) 209-3200
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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
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(202) 662-8700
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