FERMILAB-CRADA-FRA-2015-0010

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Integrable optics design principles for beam halo suppression in accelerator rings at the intensity frontier

Cooperative Research and Development Agreement Final Report

CRADA Number: FRA-2015-0010

Fermilab Technical Contact: Alexander Valishev
James Amundson

Summary Report

April 27, 2021

Fermi National Accelerator Laboratory / Kirk and Pine Street / P.O. Box 500 / Batavia, IL 60510 / 630.840.3000 / www.fnal.gov / fermilab@fnal.gov
Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy, Office of Science, Office of High Energy Physics.

NOTICE

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:
U.S. Department of Energy Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

In accordance with Requirements set forth in Article XI.A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

CRADA number: FRA-2015-0010

CRADA Title: Integrable optics design principles for beam halo suppression in accelerator rings at the intensity frontier

Parties to the Agreement: RadiaSoft, LLC and Fermi Research Alliance, LLC

Abstract of CRADA work:

RadiaSoft LLC is collaborating with Fermilab to fundamentally advance the field of particle accelerator design, in order to reduce cost and technical risk for next-generation hadron accelerators, and to more rapidly advance the intensity frontier of high energy physics. The Fermilab PI is one of the originators of the theory of integrable nonlinear magnetic lattices. Fermilab is the only laboratory in the world pursuing the experimental verification of the theory. Transferring Fermilab expertise to RadiaSoft LLC will enhance US competitiveness by enabling US industry to engage in the design of future high intensity hadron rings for spallation sources, neutrino sources, muon sources, subcritical nuclear reactors and waste transmutation facilities.

This project sought to quantify the possibilities and limitations of this fundamentally new approach to high-intensity accelerator ring design, using the parallel Synergia framework for simulations. New knowledge is expected to be gained on the following topics: a) the effects of space charge forces, field errors, magnet misalignments, and other sources of parametric resonance; b) the effect of controlled nonlinearities, such as sextupoles for chromaticity control; c) the effect of longitudinal dynamics driven by finite bunch length and rf cavities; d) how to optimally populate a Vlasov equilibrium particle distribution, perhaps via laser stripping of H- upon injection; e) optimal equilibrium distributions and methods to achieve approximately linear transverse space charge forces within the beam, and f) reexamination of relevant lattices in the literature or in present accelerators to explore potential benefits of these new design principles.

Dr. Alexander Valishev and Dr. Jeffrey Eldred provided consulting support in the physics of space charge dominated beam dynamics in the IOTA ring and other high intensity synchrotron ring designs and collaborated with RadiaSoft personnel to understand the impact of longitudinal dynamics on the stability of integrable systems.

16 December 2019

Dr. James Amundsen, Dr. Eric Stern and other members of the Synergia development team at Fermilab worked with RadiaSoft experts on the development and implementation of a new symplectic space-charge algorithm. The Synergia team provided consulting support regarding Synergia algorithms, input file development, implementation of new routines, and documentation.

Summary of Research Results:

Accelerator and beam physics (ABP) is the science of the motion, generation, acceleration, manipulation, prediction, observation and use of charged particle beams. This project was directly supported by the Small Business Innovation Research program and advanced the following ABP missions of the US Department of Energy, Office of Science, Office of High Energy Physics: advance the physics of beams to enable future accelerators; develop concepts and tools to disrupt costly technology paradigms; fully exploit science at beam R&D facilities and operational accelerators; educate and train future accelerator physicists.

The Integrable Optics Test Accelerator (IOTA) program at Fermi National Accelerator Laboratory (Fermilab) is an R&D facility for the exploration of novel concepts, such as nonlinear integrable optics, which promise to directly impact the development of future hadron rings that can advance both the Intensity Frontier and the Energy Frontier. This project provided important computational support for IOTA.

RadiaSoft developed techniques and software (https://github.com/radiasoft/rssynergia) for using Synergia, the premier Fermilab code for simulation and design of high-intensity hadron rings, to simulate the highly nonlinear features of beam dynamics in IOTA. RadiaSoft also conducted extensive simulations of IOTA under many configurations, enabling key contributions to initial IOTA commissioning. This project also enabled the development of a mathematical foundation for when and why a spectral space charge algorithm enables symplectic treatment of both self-fields and particle dynamics. A symplectic algorithm respects the conservation of phase space volume and many other important physical invariants. This algorithm has been implemented in Python for testing (https://github.com/radiasoft/rssympim) and has also been implemented using C++ in Synergia. RadiaBeam also developed efficient open boundary conditions for spectral Cartesian Poisson solvers.

The successes described above enabled RadiaBeam to collaborate with Fermilab scientists in the prototype design of a novel hadron synchrotron, building on the nonlinear optics techniques that are being explored in IOTA. This project developed a robust email-based login mechanism for RadiaSoft's Sirepo scientific gateway (https://sirepo.com),enabling the move from beta to production and subsequent productization of this cloud computing technology. RadiaSoft also developed a sophisticated browser-based GUI for Synergia (https://www.sirepo.com/synergia) which closely parallels the elegant implementation (https://www.sirepo.com/elegant). These

Sirepo-based web applications are actively used by particle accelerator schools in Korea and in the US.

Commercialization activities enabled by this project include the following. RadiaSoft is finding customers who want Sirepo-based GUIs to be developed for their scientific codes and has begun a sales effort for a subscription-based premium version of the Sirepo.com scientific gateway (https://radiasoft.net/sirepo). RadiaSoft is assisting customers on a contract R&D basis with particle accelerator design.

Related Reports, Publications, and Presentations:

https://www.osti.gov/biblio/1591641-phase-iia-final-technical-report-integrable-optics-design-principles-beam-halo-suppression-accelerator-rings-intensity-frontier

Subject Inventions listing:

None

Report Date: 27 April 2021

Technical Contact at Fermilab: Alexander Valishev and James Amundson

<u>This document contains NO confidential, protectable or proprietary information.</u>