Zachary S. Hartwig, Ph.D.

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Research Interests

The application of high-field superconducting magnets, materials science, and computational design to accelerate the demonstration and deployment of commercial fusion energy system

- Superconducting fusion magnet engineering
- Fusion energy nuclear science and device design
- Radiation damage in fusion materials
- Fusion neutronics; Monte Carlo particle transport
- Digital data acquisition and analysis systems
- Accelerator-based nuclear and material science
- Radiation and particle detector development
- Fusion plasma-material interaction science

Education

Ph.D. in Nuclear Science, MIT. February 2014.
- Concentration: Fusion nuclear science
- GPA: 4.7 / 5.0
- Thesis: *An accelerator-based in-situ diagnostic for plasma-material interactions science on magnetic fusion devices*

B.A. in Physics, Boston University. May 2005.
- Concentration: Experimental particle physics
- GPA: 3.7 / 4.0
- Degree awarded *summa cum laude*
- Recipient of Alumni Award in Physics
- Dean's List all 8 semesters

Notable Achievements

- *Recipient*, U.S. Department of Energy ORISE Postdoctoral Fellowship, Jan 2015.
- *Recipient*, MIT NSE Del Favero Prize in Nuclear Science and Engineering, May 2014.
- *Fellow*, 2013 Kavli Frontiers of Science.
- *Invited speaker*, Kavli Frontiers of Science Meeting, November, 2013.
- *USA Cycling National Champion*, Collegiate Track Division II Team Omnium. September 2012.
- *Recipient*, MIT NSE Special Award, Excellence in Science Communication and Policy. May 2012.
- *Recipient*, MIT Plasma Science and Fusion Center Award, Science Education and Outreach. July 2012.
- *Recipient*, MIT International Science and Technology Initative Global Seed Fund Grant. May 2011.
- *Recipient*, Boston University Alumni Prize for Excellence in Physics. May 2005.

Research Experience

- **Assistant professor, MIT NSE (2017-present)**: Sucessfully advanced and launched the SPARC project. Co-founded Commonwealth Fusion Systems, a spin-out company pursing commercialization of fusion energy. Co-leading the SPARC Project at MIT and overseeing several key engineering design projects including development of high-current high-temperature superconducting cables and fusion neutronics design analysis. Continuing to lead the Vault Laboratory, a facility for accelerator-based fusion nuclear science including radiation damage in HTS and structural materials. Teaching responsibilities have include 22.011 (NSE freshmen seminar), 22.033 (NSE senior design course), and 22.814 (Nuclear non-proliferation). Responsible for developing 22.061 (a new undergraduate fusion energy course).
- **Postdoctoral associate/fellow, MIT (2013-2016)**: Lead data acquisition, analysis, and computation efforts for two nuclear security projects (Low-dose monoenergetic gamma radiography system; Zero knowledge warhead verification system). Conducted on-going efforts to bring an ultracompact superconducting cyclotron to MIT for nuclear security and materials research. Proposed and lead a collaboration with MIT Aeronautics and Astronautics Engineering department on novel low-cost satellite-based particle spectrometers and dosimeters. Established a new accelerator science and detector development laboratory with collaborators. Continued development of the AIMS diagnostic for plasma-material interaction science on the Alcator C-Mod tokamak.
- **Ph.D student, MIT (2007-2013)**: Designed and demonstrated an innovative accelerator-based materials diagnostic for magnetic fusion devices. The research involved creating advanced particle transport simulations, applying radiation detection in a challenging environment, implementing a custom digital data acquisition system, and creating data analysis tools.
- **Advisor, Neotron Inc. (2009-2010)**: Collaborated on development of an innovative lithium-6-based detector for homeland security. The research involved using particle transport simulations to optimize the design and cost of the final detector.
- **Research Assistant, Boston University (2004-2006)**: Developed a particle physics simulation for the Muon g-2 Experiment (Brookhaven and Fermi National Labs). The simulation is presently used as a leading computational design tool for the next generation of the experiment. Performed experimental work on particle detection and data acquisition for the MμLAN muon lifetime experiment at Paul Sherrer Institute, Switzerland, 2005.

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Doctoral Dissertation

MIT Department of Nuclear Science and Engineering Ph.D. Dissertation

- Z.S. Hartwig (2013). *An In-situ Accelerator-based Diagnostic for Plasma-Material Interactions on Magnetic Fusion Devices.* Doctoral Dissertation, MIT, Cambridge MA, USA.
  Available for download here

Research Publications

Accelerator-based In-situ Materials Surveillance (AIMS)

- Z.S. Hartwig *et al. Fuel retention measurements in Alcator C-Mod using Accelerator-based In situ Materials Surveillance.* J. Nucl. Mat. **263** (2015) 73. doi:10.1016/j.jnucmat.2014.09.056
- Z.S. Hartwig *et al. An in-situ accelerator-based diagnostic for plasma-material interactions on magnetic fusion devices.* Rev. Sci. Instr. **84** (2013) 123503. doi:10.1064/1.4832420
- Z.S. Hartwig and D.G. Whyte. *Simulated plasma-facing component measurements for an in-situ surface diagnostic on Alcator C-Mod.* Rev. Sci. Instr. **81** (2010) 10E106. doi:10.1063/1.4832420

Magnetic fusion energy design and engineering

- Z.S. Hartwig *et al. An initial study of demountable, high-temperature superconducting magnets for the Vulcan tokamak conceptual design.* Fus. Eng. Design **87** (2012) 201. doi:10.1016/j.fusengdes.2011.10.002
- G.M. Olynyk, Z.S. Hartwig, *et al. Vulcan: a steady-state tokamak for reactor-relevant plasma-material interaction science.* Fus. Eng. Design **87** (2012) 224. doi:10.1016/j.fusengdes.2011.12.009
- G.M. Olynyk, Z.S. Hartwig, *et al. Assessing the feasibility of a high-temperature, helium-cooled vacuum vessel and first wall for the Vulcan tokamak conceptual design.* Fus. Eng. Design **87** (2012) 248. doi:10.1016/j.fusengdes.2011.12.018
- D.G. Whyte *et al. Reactor similarity for plasma–material interactions in scaled-down tokamaks as the basis for the Vulcan conceptual design.* Fus. Eng. Design **87** (2012) 234. doi:10.1016/j.fusengdes.2011.12.011
- Z.S. Hartwig and M. Zucchetti. *Neutronics studies for a compact, high-field tokamak neutron source.* Fus. Sci. Tech. **60** (2011) 725. Available online at http://www.ans.org/pubs/journals/fst/a_12471

Particle and radiation detector design, simulation, and data acquisition

- Z.S. Hartwig. *The ADAQ framework: An integrated toolkit for data acquisition and analysis with real and simulated radiation detectors.* Nucl. Instr. and Meth. A *In Press*, 2016. doi:10.1016/j.nima.2016.01.017
- Z.S. Hartwig and P. Gumplinger. *Simulating response functions and pulse shape discrimination for organic scintillation detectors with Geant4.* Nucl. Instr. and Meth. A **737** (2014) 155. doi:10.1016/j.nima.2013.11.027
- A. Inglis *et al. Glass panel Lithium-6 Detector.* IEEE Conference on Homeland Security (2012). doi:10.1109/THS.2012.6459887

Experimental particle physics (The Muon Lifetime Analysis (MμLAN) experiment)

- D.M. Webber *et al. Measurement of the positive muon lifetime and determination of the Fermi constant to part-per-million precision.* Phys. Rev. Lett. **106** (2011) 041803. doi:10.1103/PhysRevLett.106.041803
- V. Tishchenko *et al. Detailed report of the MuLan measurement of the positive muon lifetime and determination of the Fermi constant.* Phys. Rev. D. **87** (2013) 052003. doi:10.1103/PhysRevD.87.052003

Reference Publications

A comprehensive physics and mathematics reference for magnetic fusion

- Z.S. Hartwig and Y.A. Podpaly. *The Magnetic Fusion Energy Formulary.* Self-published, 2016. Available online at http://www-internal.psfc.mit.edu/research/MFEFormulary.

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Teaching Experience

- **Lead instructor**: MIT 22.033 - NSE senior design course
- **Lead instructor**: MIT 22.011 - NSE freshmen seminar course
- **Co-instructor**: MIT 22.814 - NSE nuclear non-proliferation course
- **Teaching assistant**: MIT 22.15 Essential Numerical Methods (Prof. I. Hutchinson). Fall 2013.
- **Teaching assistant**: MIT 22.63 Engineering Principles for Fusion Reactors (Prof. D. Whyte). Spring 2012.
- **Teaching assistant**: MIT 22.105 : Electromagnetic Interactions (Prof. D. Whyte). Fall 2010.
- **UROP advisor**: Supervised over 10 UROPs during time at MIT
- **Undergraduate thesis mentor**: Lauren Chilton (2012), Monica Phama (2018), Nick Schwartz (2018)
- **Private tutor**: High school physics for several Boston University Academy Students. 2005-2006.

Leadership Experience

- **Organizer**: U.S. fusion student advocacy trip to 30 Congressional offices in Washington DC. June 2012.
- **Mediator**: Conflict resolution, MIT Resistance for Easing Friction and Stress Program. January 2010.

Hardware Expertise

Data Acquisition

- CAEN S.p.A. high-performance detector data acquisition systems
- Raspberry Pi / Pi-plates data acquisition systems
- Tektronix digital oscilloscopes and signal generators

Particle Detector Construction

- Scintillator crystals, photomultiplier tubes, silicon avalanche photodiodes, silicon photomultiplier, signal preamplifiers, microcontrollers, soldering, basic machining, vacuum hardware, detector test platforms

Computer expertise

Programming Languages

- C, C++, Python, IPython/IPython notebooks, Open MPI, Unix shell scripting, GNU make, Matlab, IDL, HTML

Particle Transport and Nuclear Physics Codes

- Geant4, MCNP6/5/X, DAGMC CAD-based neutronics, SRIM/TRIM, EASY, NJOY, TALYS, EMPIRE

Data acquisition, storage and analysis

- ROOT, MDSplus
- Lead developer of the ADAQ framework

Computer-Aided Design (CAD) and Analysis

- Solid Edge ST5, CUBIT Tool Suite, COMSOL Multiphysics

Cloud Computing

- Amazon Web Services (EC2 Cloud Compute Framework)

Productivity Software

- Windows OS, Linux OS (Fedora, RHEL, Ubuntu), Emacs, Subversion, Git, GitHub, LaTeX, GIMP, Inkscape