John Adams Institute for Accelerator Science

Education & Training in Accelerator Science

Student Handbook and Programme Syllabus

2017-2018

John Adams Institute for Accelerator Science

The John Adams Institute for Accelerator Science (JAI)

The John Adams Institute for Accelerator Science (JAI) is a centre of excellence in the UK for advanced and novel accelerator technology, providing expertise, research, development and training in accelerator techniques, and promoting advanced accelerator applications in science and society. The JAI programme is organised around three pillars: research in accelerator science; training the next generation of accelerator scientists; and science outreach to industry and the public. The JAI is jointly hosted by the physics departments of the University of Oxford, Royal Holloway, University of London and Imperial College London.

What the JAI Does

The next generation of particle physics needs the next generation of particle accelerators. The JAI is a UK and world-leading research group dedicated to the research and development of particle accelerators.

We are working on the next generation colliders – the Future Circular Collider (FCC), including the Higher-Energy LHC (HE-LHC), and the linear colliders of the International Linear Collider (ILC) and Compact Linear Collider (CLIC) collaborations. These machines may become the next particle accelerators designed to complement the discoveries made at the Large Hadron Collider (LHC) at CERN.

Modern light sources, synchrotron-based and free electron lasers, are indispensable for scientific and technological development of the modern economy and society. We are working on improving light sources such as Diamond, designing the New Light Source and working on further ideas.

A very challenging, but very promising direction is the creation of compact light sources and accelerators for particle physics based on laser plasma acceleration. The JAI has a unique combination of research teams working together to address this challenge, see in particular the pages of Simon Hooker's team at the University of Oxford and the pages of JAI at Imperial. JAI is also a member of the Helmholtz Virtual Institute and of the EUPRAXIA project.

In addition to the high-energy frontier, accelerators are also required at the so-called 'intensity' frontier, usually providing very high power beams of hadrons in order to produce secondary particles such as neutrons, muons or neutrinos. This research area addresses upgrades to existing machines (including the LHC) to increase the intensity, as well as research to understand fundamental properties of beams at high intensity using a scaled experiment called 'IBEX'. This could lead to breakthroughs in hadron beam accelerators leading to better scientific facilities, easier access to radioisotopes in medicine or even methods to reduce the lifetime of nuclear waste through accelerator driven transmutation.

Large particle accelerators for particle physics make up just a handful of the 35,000 accelerators in the world. Smaller particle accelerators are used in applications closer to home such as in archaeology, zoology and medicine. In particular, JAI collaborates with the Oxford Institute for Radiation Oncology on the development of particle accelerators for the treatment of cancers.

The JAI Graduate Accelerator Physics Programme

Accelerator Physics Course

Term I (Michaelmas Term 2017)

This is the first half of a series to be completed in Term II (Hilary Term 2018). The format in Michaelmas Term 2017 is 22 one-hour lectures supplemented by four two-hour Exercise Classes. The course includes a basic grounding in particle accelerators (transverse and longitudinal dynamics, beam imperfections, RF acceleration beam diagnostics & instrumentation, and synchrotron radiation) as well as in plasma physics and lasers to prepare students for the invention of laser-driven devices for particle acceleration.

The aim of the Exercise Classes is to show the students how to use standard simulation and design software tools which calculate one of the important design features of an accelerator. Specialists in the fields of machine lattice, cavities and magnets will lead the classes. At the end of each class students should be able to run simple data input sets for each program.

Lecture Programme

The Spectrum of Particle Accelerators

This lecture provides an overview of the development of accelerators throughout history, including some of the key innovations such as phase stability and focusing principles. After this lecture, students should be able to explain the basic operating principles of a range of different types of accelerators including: electrostatic accelerators, linear accelerators, cyclotrons, synchrotrons and fixed-field alternating-gradient accelerators.

Live Connection – LHC Control Centre CERN

This is a special lecture consisting of a live connection with the control centre of the LHC and its injectors at CERN, Geneva and presentation by LHC operation crew. It includes an overview of accelerator operations and activities of operations teams to ensure performance of accelerator complex. A summary of key accelerator parameters and their *in situ* measurement at the LHC will also be given.

Applications of Accelerators

This lecture provides overview of applications of accelerators to a variety of fields. Applications in the fields of particle physics, medicine, industry, and the physical, environmental and life sciences will be highlighted.

Transverse Optics I & II

This series of two lectures gives an introduction to transverse dynamics in periodic accelerators. The first lecture takes students through a treatment of focusing in cyclotrons and weak focusing in synchrotrons, introduces the multipole description of magnetic fields and motivates strong (alternating gradient) focusing. The second lecture starts by considering the Hamiltonian for particle motion in an electromagnetic field and briefly derives the equation of motion (Hill's equation) and its solution. This lecture introduces the concepts of transfer matrices, stability of focusing, betatron tune, and phase space.

Longitudinal Beam Dynamics and Momentum Effects

This series of two lectures provides an introduction to longitudinal beam dynamics in the periodic accelerators. The lectures include phase stability in a repetitive acceleration system; transition and momentum compaction; and the effect of momentum spread.

RF Cavities (I, II, and III) and RF Cavity Design

The three lectures introduce the principles and design of microwave cavities for acceleration, phase and group velocity – transit time factor and shunt impedance. This series also includes an introduction to the simulation of cavities using specialised software, such as SUPERFISH and CST.

Electron Dynamics, Synchrotron Radiation (I, II), Wigglers & Undulators

This series of four lectures concentrates on synchrotron radiation and its effects on electron beam dynamics in storage rings. It includes an introduction to the properties of synchrotron radiation and synchrotron light sources. The series covers in detail the angular distribution of the power radiated by accelerated particles as well as the angular and frequency distribution of the radiated energy. It also covers the physics principles of radiation from wigglers and undulators.

Accelerator Plasma Physics

This series on accelerator plasma physics consists of three lectures. The series provides basic concepts in accelerator plasma physics, an introduction to laser-plasma-based ion accelerators and an introduction to plasma wake-field accelerators. The lectures will allow students to identify synergies between particle accelerators, lasers and plasma.

Beams and Imperfections

This lecture introduces topics that result in imperfections in an accelerator design and operation. Topics covered include resonant conditions, closed-orbit distortion, gradient errors, and chromaticity corrections.

Beam Diagnostics and Instrumentation

This lectures covers introductory topics of beam diagnostic methods and instrumentation for their measurement. It includes topics such as the observation of beam and the measurement of beam current; the beam lifetime in a storage ring; the measurement of the momentum and energy of a particle beam; the measurement of the transverse beam position; and the measurement of beam optical parameters.

Parameters for Student Project Design

This lecture introduces the Student Design Project of Hilary Term 2018. This year's project will be on the Higher-Energy LHC (HE-LHC). The lecture will present the HE-LHC as a future energy upgrade of the LHC. The HE-LHC foresees new 20-T dipole magnets in the LHC arcs, providing a proton-proton centre-of-mass energy of 33 TeV. The lecture presents a concise description of the layout and parameters of the proposed HE-LHC, and discusses their main accelerator-physics and technology challenges that will be studied further in Hilary Term 2018.

Exercise Classes

Four Exercise Papers are due for Term I (Michaelmas Term 2017) and will be marked as part of the course assessment. Students should submit their answers to the Exercise Papers at the Exercise Classes, which are usually held on Thursday afternoons):

1. Transverse Optics (Week 3)
2. Longitudinal Dynamics (Week 5)
3. RF Cavities (Week 7)
4. Synchrotron Radiation (Week 8)

Term II (Hilary Term 2018)

In Term II (Hilary Term 2018), topics which will be covered in the lectures are: magnet design, non-linear dynamics, beam transport, space-charge effects, beam-beam effects, linear colliders & free-electron lasers, vacuum & surface science, injection & extraction, and electron & ion sources.

The lectures will be supplemented by weekly tutorials that will apply the skills learned in the first term to prepare the Student Design Project for the study of a new accelerator. Participating students will hand in draft chapters of different parts of a design review report for marking at each of the tutorials. For 2017-2018, the Student Design Project will be on the study of the Higher–Energy LHC (HE-LHC). The HE-LHC is a future energy upgrade of the LHC. It foresees new 20-T dipole magnets in the LHC arcs, providing a proton-proton centre-of-mass energy of 33 TeV. Aspects of the lattice, magnet system and RF acceleration will be studied as part of the design. The students will prepare a Design Report and deliver a JAI Seminar on their study.

Course Resources

The course resources are available here and include the lecture timetables, slides and documents as well as information on the video conferencing connection.

Education Visit to CERN

As part of the graduate course, a visit to CERN is organised at the end of the Student Design Project. The visit programme includes tours of the accelerator facilities of the Laboratory, including the LHC and other accelerator facilities that groups from the JAI and the member universities participate. The visit to CERN also includes a presentation by the students of their design project at a seminar with expert accelerator physicists. Students should make their research supervisors aware of this and advise the course lecturers of any unavailable periods between March and June 2018 in order to assist with the planning.

Assessment

The graduate course Accelerator Physics consists of 4 compulsory Exercise Papers in Michaelmas Term 2017 and a Student Design Project in Hilary Term 2018. The four Exercise Papers have equal weighting that make up the overall mark for Michaelmas Term 2017. The Student Design Project is examined along the following four criteria with the relative weighting and makes up the overall mark for Hilary Term 2018:

Introduction Exercise Paper (15%)
Development of Design Project (40%)
Final Report (30%)
Seminar Presentation (15%)

Further general information for graduate students is available in the following respective handbooks:

University of Oxford

Imperial College London

Royal Holloway, University of London

Course Evaluation

Students will be invited to provide feedback on the course. This includes a presentation of their work to the next meeting of the JAI Advisory Board, which is expected to be held in April 2018. Students will have the opportunity to discuss their course experience with the members of the JAI Advisory Board. A questionnaire will also be sent to all students for further feedback.

Recommended Textbooks

The underlying texts are *An Introduction to Particle Accelerators* by Edmund Wilson (OUP) IBSN 0 19 850829 8 and *Unifying Physics of Accelerators, Lasers and Plasma* by Andrei Seryi (CRC Press) ISBN 978-1-4822-4058-0.

Engines of Discovery by Andrew Sessler and Edmund Wilson (WSP) IBSN 978-981-270-071 and *Engines of Discovery – Revised and Extended* by Andrew Sessler and Edmund Wilson (WSP) ISBN 978-9814417198 are recommended as background reading.

Additional textbooks and reading recommendations for specific sub-topics will be supplied by the course lecturers during term.

The JAI Undergraduate Accelerator Physics Programme (Oxford only)

S19 Short Option - Unifying Physics of Accelerators, Lasers and Plasma

Short Options are intended to introduce either specialist topics or subjects outside the mainstream courses. They allow students to experiment with new material without significant prejudice to their degree class, as they carry a low weighting. The full description is provided in the Undergraduate Student Handbook.

The S19 short option undergraduate course *Unifying Physics of Accelerators, Lasers and Plasma* consists of 12 introductory lectures over a 4-week period that is offered to undergraduate students of the University of Oxford during Trinity Term (April-June 2018). It is examined in a 1.5 hr paper. In addition to covering key accelerator concepts and techniques, the course also examines key innovative future developments and applications of accelerator science. The course emphasises the exciting synergies of accelerators, lasers and plasma and brings together contributions from electrodynamics, classical mechanics, laser and plasma science. This course is aimed at those who are interested in exploring the exciting science arising from the synergy of the three areas of accelerators, lasers and plasma, which is essential for the creation of the next generation facilities, devices and scientific instruments.

In particular, the course will explore novel laser-plasma acceleration methods comparing them to traditional accelerators. The students will study the design of national scale as well as compact Free Electron Lasers. We will study what would it take to make a next generation particle therapy facility based on plasma acceleration, studying the effect of radiation on DNA as well as elements of medical imaging. The course will explore the designs of colliders which could be built after the LHC. The course will highlight similarities and differences of terminology and mathematical apparatus used for the description of similar phenomena in these areas of physics, building bridges of understanding between accelerators, lasers and plasma. The students will be introduced to these three areas of physics in tandem with the industrial methodology of inventiveness to connect the areas further, and to stimulate the students for taking on the challenges of scientific and technological innovation. The S19 course will also include a live link-up with the LHC control centre at CERN in Geneva for a presentation of this unique facility and a Q&A session with experts.

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Additional Information

Summer Studentships

Oxford University Internship Programme (to CERN)

Interns in their 3rd year of their 4-year course in Physics or Engineering are invited to apply to the Oxford University Internship Programme (to CERN). The selected students will attend the CERN Summer Student Programme lectures and work on an accelerator-based project.

Oxford Summer Student Placement

The JAI is providing summer project opportunities at Oxford - see this link for the Summer Placement Programme.

Joint JAI – Cockcroft Institute Advanced Lecture Programme

JAI is also providing advanced graduate courses jointly with the Cockcroft Institute (CI). The Joint JAI-CI Advanced Lectures is a series of lectures on accelerator science and technology delivered by the UK's two leading institutes in accelerator science. The courses are at the advanced level and students are expected to have completed an introductory level course in accelerator science. More information is available at JAI-CI page and this link.

Public Engagement

Accelerate! Show

The *Accelerate! Show* is an award-winning, live, interactive science show aimed at audiences of high school pupils. The show uses a series of exciting demonstrations from exploding hydrogen balloons and liquid nitrogen with levitating superconductors through to giant beach balls - all to tell the story of how particle accelerators work. All JAI students are welcome to join the team to learn to present the show (or help backstage, if you do not like to be in the spotlight), and to learn how to safely perform some fantastic demonstrations and gain confidence in your presenting ability. Past presenters are regularly invited to speak at high-profile events and on TV and radio. The script, demonstration and information are available online. Students are more than welcome to adapt the show to their own research interests. Contact Dr. Suzie Sheehy for more information.

Accelerator and Particle Physics Education at A-Level (APPEAL)

Since 2010, the JAI organises in collaboration with CERN a one-day annual school to give A-level teachers an opportunity to learn about the phenomena and scientific challenges which connect astrophysics, particle physics and the physics of particle accelerators. This school is designed for physics teachers who are not necessarily physics specialists. Preference will be given to teachers coming from schools which usually send very few pupils to University.

The schools address questions such as "How does a particle accelerator work?" "What are the questions the LHC will answer?" "How does an experiment at the LHC work?" "What are the applications of particle accelerators in our daily lives?" and "What is the origin of the Universe and of matter?"

Further information is available on the APPEAL site here.

JAI Events

JAIFest – The full day annual JAIFest that is held at the end of Michaelmas Term 2017 includes presentations from academic staff and graduate students. Graduate students are expected to attend. The next JAIfest will be held at the University of Oxford on Thursday, 7 December.

JAI Lecture Series – The series of seminars are delivered by distinguished lecturers from JAI and from laboratories / universities world-wide. The seminars are scheduled so that that graduate student body can attend. Further information is available here.

Lecturers (Term I - Michaelmas Term 2017)

Prof. Riccardo Bartolini (Diamond Light Source & Oxford)
Dr. R Bodenstein (Oxford)
Prof. Stewart Boogert (RHUL)
Dr. Stuart Mangles (ICL)
Dr. Ciprian Plostinar (European Spallation Source)
Dr. Aakash Sahai (ICL)
Prof. Andrei Seryi (Oxford)
Dr. Suzie Sheehy (Oxford)
Prof. Emmanuel Tsesmelis (CERN & Oxford)