USPAS Program

Sponsoring University:

Old Dominion University

Course:

Beam Physics with Intense Space Charge

Instructors:

Steven Lund, Michigan State University/Facility for Rare Isotope Beams (MSU/FRIB)
John Barnard, Lawrence Livermore National Laboratory (LLNL)

Recitations/Grading:

Daniel Winklehner, Massachusetts Institute of Technology (MIT)

Purpose and Audience

The purpose of this course is to provide a comprehensive introduction to the physics of beams with intense space charge. This course is suitable for graduate students and researchers interested in accelerator systems that require sufficient high intensity where mutual particle interactions in the beam can no longer be neglected.

Prerequisites

Undergraduate level Electricity and Magnetism and Classical Mechanics. Some familiarity with basic accelerator physics, plasma physics, and special relativity is strongly recommended.

It is the responsibility of the student to ensure that he or she meets the course prerequisites or has equivalent experience.

Objectives

This course is intended to give the student a broad overview of the dynamics of beams with strong space charge. The emphasis is on theoretical and analytical methods of describing the acceleration and transport of beams. Some aspects of numerical and experimental methods will also be covered. Students will become familiar with standard methods employed to understand the transverse and longitudinal evolution of beams with strong space charge. The material covered will provide a foundation to design practical architectures.

Instructional Method

Lectures will be given during morning sessions, followed by afternoon discussion sessions, which will engage the student on the material covered in lecture. Daily problem sets will be assigned that will be expected to be completed outside of scheduled class sessions. Problem sets will generally be due the morning of the next lecture session. A final take home exam will be given on the second Thursday, and will cover the contents of the entire course. Two instructors and the recitation lecturer/grader will be available for guidance during evening homework sessions.

Course Content
In this course, we will introduce you to the physics of intense charged particle beams, focusing on the role of space charge. The topics include: particle equations of motion, the paraxial ray equation, and the Vlasov equation; 4-D and 2-D equilibrium distribution functions (such as the Kapchinskij-Vladimirskij, thermal equilibrium, and Neuffer distributions), reduced moment and envelope equation formulations of beam evolution; transport limits and focusing methods; the concept of emittance and the calculation of its growth from mismatches in beam envelope and from space-charge non-uniformities using system conservation constraints; the role of space-charge in producing beam halos; longitudinal space-charge effects including small amplitude and rarefaction waves; stable and unstable oscillation modes of beams (including envelope and kinetic modes); the role of space charge in the injector; and algorithms to calculate space-charge effects in particle codes. Examples of intense beams will be given primarily from the ion and proton accelerator communities with applications from, for example, beam sources and low energy beam transport and acceleration, beam driven high-energy-density physics and heavy-ion fusion, spallation neutron sources, accelerator driven systems for nuclear waste transmutation, etc.

Reading Requirements
Extensive class notes will be provided that will serve as the primary reference. A paper copy will be provided by the USPAS. Notes will be archived and updated on the course web site:

https://people.nscl.msu.edu/~lund/uspas/bpisc_2015/

Supplemental text to be provided: "The Theory and Design of Charged Particle Beams" Second Edition, Updated and Expanded by Martin Reiser, Wiley & Sons 2008.

Credit Requirements
Students will be evaluated based on performance: final exam (20 % of course grade), homework assignments (80 % of course grade).

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