CAS Basics of Accelerator Physics and Technology

Report of Contributions

https://indico.cern.ch/e/1200893

Contribution ID: **1** Type: **not specified**

Accelerators for Beginners and the CERN Complex

Monday 9 May 2022 08:45 (1 hour)

Presenter: Dr STEERENBERG, Rende (CERN)

Contribution ID: **2** Type: **not specified**

Basic Mathematics and Units

Monday 9 May 2022 09:55 (1 hour)

Presenter: Dr STEERENBERG, Rende (CERN)

Contribution ID: **3** Type: **not specified**

Electromagnetic Theory

Monday 9 May 2022 11:25 (1 hour)

The lecture is a refresher at the level of high school and the first year of engineering school. It covers electrostatics (Coulomb force, electric field, potential energy and Gauss Law), magnetostatics (magnetic forces, Amperes law, magnetic moments, magnets), electric and magnetic induction (Faraday Law, Ampere-Maxwell Law), Maxwell equations in integral and differential forms and electromagnetic waves in vacuum.

Presenter: SKOWRONSKI, Piotr Krzysztof (CERN)

Contribution ID: **4** Type: **not specified**

Relativity for Accelerators

Monday 9 May 2022 13:50 (1 hour)

The goal of this lecture is to introduce the basic concepts of special relativity without overloading formulas. The theory of special relativity, originally proposed by Albert Einstein in his famous 1905 paper, has profoundly affected our view of physics, space, and time. This lecture briefly introduces the concepts behind special relativity, including length contraction, time dilation, the Galilean and Lorentz transformations, relativistic kinematics, Doppler shifts, practical application of the theory and more.

Presenter: SHREYBER, Irina (Tomsk State University (RU))

Contribution ID: **5** Type: **not specified**

Particle Sources

Monday 9 May 2022 15:00 (1 hour)

The lecture delivers a basic overview of the terms and principles of particle production and extraction, including some plasma physics and a general ion source model. This information is further elaborated with the help of some examples of electron sources and ion sources.

Presenter: KUCHLER, Detlef (CERN)

Contribution ID: **6** Type: **not specified**

Standard Model and Beyond

Monday 9 May 2022 16:30 (1 hour)

We review the basic principles that lead to our current understanding of the fundamental elements of matter and their interactions, as codified in the so-called Standard Model of particle physics. Starting from the two pillars, Quantum Mechanics and the Special Theory of Relativity, and the resulting picture of interactions as the result of particle exchange, we will address the question of how particles acquire mass, the solution offered by the Brout-Englert-Higgs mechanism, and the discovery and current understanding of the so-called Higgs boson —the particle of the vacuum. We will then summarise the reasons for which, despite its success in describing essentially all experimental observations, the Standard Model is still considered to be only an effective theory, en route to some deeper, perhaps ultimate theory, along with some select examples of searches for New Physics. Finally, we will have a look at what we expect to learn from the current runs of the LHC, the HL-LHC, and eventually some future collider programs.

Presenter: SPHICAS, Paris (CERN/Athens)

Contribution ID: **7** Type: **not specified**

Transverse Beam Dynamics I

Tuesday 10 May 2022 08:45 (1 hour)

This lecture gives an introduction to the dynamics of the transverse motion of the particles in an accelerator or storage ring. Following the general tenor of the school, special focus is put on a basic level of the explanations and so
tedious mathematical deductions are avoided and replaced by logical arguments and equivalent descriptions in other fields of physics.
As a consequence the lectures give a simplified but consistent introduction to the basic concepts: The equation of motion, the matrix description of focusing and defocusing magnets, and single-particle trajectories are explained. Referring to the beam as an ensemble of many particles the concept of beta function and emittance is introduced as a quality parameter for the particle ensemble and transverse size of the beam. Dispersion and Chromaticity are explained to describe the effect of the finite energy spread of the beam and the luminosity of a particle collider is shown based on the example of the LHC.
Whenever possible the emphasis is put on the physics behind the equations and the understanding of the fundamental design principles.

Presenter: Dr HOLZER, Bernhard (CERN)

Contribution ID: **8** Type: **not specified**

Transverse Beam Dynamics II

Tuesday 10 May 2022 13:50 (1 hour)

This lecture gives an introduction to the dynamics of the transverse motion of the particles in an accelerator or storage ring. Following the general tenor of the school, special focus is put on a basic level of the explanations and so
tedious mathematical deductions are avoided and replaced by logical arguments and equivalent descriptions in other fields of physics.
As a consequence the lectures give a simplified but consistent introduction to the basic concepts: The equation of motion, the matrix description of focusing and defocusing magnets, and single-particle trajectories are explained. Referring to the beam as an ensemble of many particles the concept of beta function and emittance is introduced as a quality parameter for the particle ensemble and transverse size of the beam. Dispersion and Chromaticity are explained to describe the effect of the finite energy spread of the beam and the luminosity of a particle collider is shown based on the example of the LHC.
Whenever possible the emphasis is put on the physics behind the equations and the understanding of the fundamental design principles.

Presenter: Dr HOLZER, Bernhard (CERN)

Contribution ID: **9** Type: **not specified**

Transverse Beam Dynamics III

Wednesday 11 May 2022 08:45 (1 hour)

This lecture gives an introduction to the dynamics of the transverse motion of the particles in an accelerator or storage ring. Following the general tenor of the school, special focus is put on a basic level of the explanations and so
tedious mathematical deductions are avoided and replaced by logical arguments and equivalent descriptions in other fields of physics.
As a consequence the lectures give a simplified but consistent introduction to the basic concepts: The equation of motion, the matrix description of focusing and defocusing magnets, and single-particle trajectories are explained. Referring to the beam as an ensemble of many particles the concept of beta function and emittance is introduced as a quality parameter for the particle ensemble and transverse size of the beam. Dispersion and Chromaticity are explained to describe the effect of the finite energy spread of the beam and the luminosity of a particle collider is shown based on the example of the LHC.
Whenever possible the emphasis is put on the physics behind the equations and the understanding of the fundamental design principles.

Presenter: Dr HOLZER, Bernhard (CERN)

Contribution ID: **10** Type: **not specified**

Longitudinal Beam Dynamics I

Tuesday 10 May 2022 11:25 (1 hour)

Contains the course material for the part I and part II.
The lectures present an introduction to longitudinal beam dynamics on a basic level, focused rather on the concepts than the mathematical details.
It covers the basic methods of acceleration in a linac, presents different circular accelerator types, and focuses more on the longitudinal beam dynamics in synchrotrons.
The operation principle of synchrotrons is described, synchrotron oscillations in energy and phase are discussed, together with their representation in phase space, and their stability conditions presented.
The lecture also shows the importance of a proper matching of the longitudinal parameters when the beam is transferred from one accelerator to the next.
Finally, the RF manipulations in the PS for the generation of the bunch structure of the LHC beam are explained.

Presenter: Dr FRANK, TECKER (CERN)

Contribution ID: **11** Type: **not specified**

Normal-Conducting Magnets

Tuesday 10 May 2022 09:55 (1 hour)

This lecture will focus on normal-conducting, iron-dominated accelerator magnets. In the beginning, we will explain the basic principles and technologies, how such magnets are designed and built, and what is their primary function in a modern particle accelerator. We will show interesting examples from the past and finally we will discuss whether normal-conducting magnets will play a strategic role in future accelerator projects.

Presenter: ZICKLER, Thomas (CERN)

Contribution ID: **12** Type: **not specified**

Discussion Session

Tuesday 10 May 2022 15:00 (1 hour)

Contribution ID: **13** Type: **not specified**

Discussion Session

Wednesday 11 May 2022 16:30 (1 hour)

Contribution ID: **14** Type: **not specified**

Discussion

Thursday 12 May 2022 13:50 (1 hour)

Contribution ID: **15** Type: **not specified**

Discussion

Friday 13 May 2022 16:30 (1 hour)

Contribution ID: **16** Type: **not specified**

Collective effects

Friday 13 May 2022 08:45 (1 hour)

The performance of most accelerators is linked to the amount and/or the density of the particles in the beam. The collective interactions of the charged particles within the beam usually sets the limit on these quantities, their understanding and mitigation is therefore crucial to maximise the performance of the machines. In this lecture we will address the basic principles of the various mechanisms of interactions that can deteriorate the beam quality, such as beam instabilities driven by electromagnetic wake fields or electron clouds, non-linear effects driven by space-charge forces or beam-beam interactions as well as scattering effects.

Presenter: BUFFAT, Xavier (CERN)

Contribution ID: **17** Type: **not specified**

Plasma Wakefield Acceleration + AWAKE

Friday 13 May 2022 09:55 (1 hour)

The construction of ever larger and costlier accelerator facilities has its limits, and new technologies will be needed to push the energy frontier. Plasma wakefield acceleration is a rapidly developing field which appears to be an auspicious candidate technology for future high-energy accelerators providing acceleration gradients with a factor 10 to 1000 larger than in conventional radio-frequency metallic cavities used in current accelerators.
This presentation introduces the plasma wakefield acceleration physics and technology, shows the technological challenges, gives an overview of the state of the art and shows promising results on the example of the advanced proton-driven plasma wakefield experiment, AWAKE, at CERN.

Presenter: GSCHWENDTNER, Edda (CERN)

Contribution ID: **18** Type: **not specified**

HL-LHC

Friday 13 May 2022 11:25 (1 hour)

The HL-LHC upgrade project will enable a tenfold increase in integrated luminosity delivered to the ATLAS and CMS experiments by the LHC. Achieving this objective started already recently by an upgrade of the machine protection, collimation and shielding systems during the second long shutdown (LS2) of the LHC, and is followed by the deployment of novel key technologies, including Nb3Sn based insertion regions and final focusing magnets, cold powering by MgB2 superconducting links and integration of Nb crab-cavities to compensate the effects of a larger crossing angle. After a period of intensive R&D and prototyping, the project is now entering the phase of industrialization and series production for all main components. In this presentation, an overview of the project status and plans for deployment and the machines performance ramp-up in Run 4 is presented. Progress on the validation of key technologies, status of prototypes and series production as well as the final integration studies for the HL equipment are summarized. These are accompanied by the imminent completion of major civil works and the start of infrastructure installations. Initial operational experience will be gained at the Inner Triplet String, presently in assembly at CERN's Superconducting Magnet Test Facility, which will enable a fully integrated test of the main magnets, powering, and protection systems in an HL-LHC final focusing configuration.

Presenter: ZERLAUTH, Markus (CERN)

Contribution ID: **19** Type: **not specified**

Future Linear Colliders

Friday 13 May 2022 13:50 (1 hour)

A Higgs factory is considered the highest-priority next collider in the EPPSU 2020 strategy update. Two linear colliders projects, the Compact Linear Collider (CLIC) and the International Linear Collider (ILC), currently under study are among the candidates being considered. CLIC uses X-band normal conducting technology operated at 70-100 MV/m, while ILC is based on Super-Conducting RF structures at 31.5 MV/m. Both can be upgraded to multi-TeV collisions. Although the linacs accelerating the particles use different RF technologies they share similar challenges, for example related to nanobeams, injectors and positron production. The talk will summarize recent developments and the current status of the two projects, including their baselines parameters, on-going technology and performance studies, near future plans and international planning.

Presenter: STAPNES, Steinar (CERN)

Contribution ID: **20** Type: **not specified**

Future Circular Colliders

Friday 13 May 2022 15:00 (1 hour)

The Future Circular Collider (FCC) study is developing designs for a new research infrastructure to host the next generation of higher performance particle colliders to extend the research currently being conducted at the LHC, once the High-Luminosity phase (HL-LHC) reaches its conclusion in around 2040. The goal of the FCC is to push the energy and intensity frontiers of particle colliders, with the aim of reaching collision energies of 100 TeV, in the search for new physics. An international collaboration of more than 150 universities, research institutes and industrial partners from all over the world are developing possibilities for circular colliders, new detector facilities, the associated infrastructure, cost estimates, global implementation scenarios, as well as appropriate international governance structures. The FCC examines scenarios for three different types of particle collisions: hadron (proton–proton and heavy ion) collisions, like in the LHC (FCC-hh) electron–positron collisions (FCC-ee), as in the former LEP. Other options include proton–electron collisions or proton-heavy ion collisions.

Presenter: BUFFAT, Xavier (CERN)

Contribution ID: **21** Type: **not specified**

Injection and Extraction

Thursday 12 May 2022 08:45 (1 hour)

The storage and acceleration of particles in a synchrotron are typically limited to a range of energy, or magnetic rigidity, of a factor 15. Therefore, to accelerate protons from the 200 MeV Linac 4 to the 7 TeV it comes that a chain of at least 4 such synchrotrons is needed.
The injection and extraction of beams between accelerators are essential to achieve a wide range of energies and a beam specification.
This lecture presents injection and extraction techniques used for synchrotrons and across the CERN complex. A specific emphasis is placed on introducing the concepts and highlighting concrete examples of the different schemes.

Presenter: DUTHEIL, Yann (CERN)

Contribution ID: **22** Type: **not specified**

Superconducting Magnets

Wednesday 11 May 2022 15:00 (1 hour)

In this lecture we first discuss the requirements of the magnets in terms of aperture and beam size, the relations between dipole field and accelerator energy, and conditions of beam stability on the quadrupole gradient. We then show how the superconducting technology enables a technological leap, with current densities in the windings 100 times larger than what can be achieved with resistive conductors. It took more than 50 years from the superconductivity discovery to the construction of sc magnets in the range of a few tesla: we will briefly outline the obstacles that had to be overcome, leading to the development of cables made of multifilamentary strands embedded in a copper matrix. A low-temperature superconductor can provide dipole fields up to 9 T (Nb-Ti) and 16 T (Nb3Sn). We conclude by outlining two areas in which superconducting magnets for accelerators reach the technological limit: the management of forces and stresses induced by electromagnetic forces and the challenges related to the magnet protection

Presenter: TODESCO, Ezio (CERN)

Contribution ID: **23** Type: **not specified**

Linear Imperfections

Thursday 12 May 2022 11:25 (1 hour)

A real accelerator may deviate significantly with respect to the ideal model due to manufacturing and installation uncertainties. Such deviations or imperfections impact many aspects like machine apertures, optics quality and performance, and they must be corrected to limit or minimize their impact of the beam. This lecture discusses the uncertainties affecting the linear machine: errors in dipole and quadrupolar fields as well as misalignment and their impact on orbit and optics. The concepts to compensate the errors are outlined. The impact of tides and vibrations are presented as example of how dynamically varying imperfections may impact a large accelerator like the LHC.

Presenter: WENNINGER, Jorg (CERN)

Contribution ID: **24** Type: **not specified**

Controls

Thursday 12 May 2022 15:00 (1 hour)

The control system provides means to interact with the accelerators to the physicists and operators. Key Control System requirements are Settings management and control, acquisition with possible post-processing, long-term data logging, automation, and monitoring and diagnostics. Whenever possible, the Control System is based on industrial solutions for both the hardware and the software. However, several domains call for a custom solution and, in those cases, established standards and commercial-off-the-shelf (COTS) are used to build the system. With the rapid evolution of the CPUs available on the market, the Control Systems are now very capable compared to the early systems. There are still several systems, such as the CERN Control System, EPICS, and Tango, but a modern Control System is typically based on 3 hardware layers: The resource tier close to the accelerator hardware, the server tier with the central computing infrastructure, and the client tier installed in the Control rooms. Software-wise, the lower tier is dedicated to real-time processing with programs running on the Front-End Computers (FEC). The middle tier, or business tier, hosts the general and control-specific high-level services, while the top tier, the presentation tier, runs the Graphical User Interfaces (GUI). At CERN, the setting management system (LSA) will translate high-level values into low-level hardware values before sending them to the real-time control driven by the Central Timing system. For acquisition logging and post-processing, systems such as NXCALS and UCAP are used.

Presenter: DEGHAYE, Stephane (CERN)

Contribution ID: **25** Type: **not specified**

Vacuum Systems

Thursday 12 May 2022 16:30 (1 hour)

Vacuum systems are an intrinsic part of any accelerators around the world: all particles are circulating under vacuum. This lecture gives rudiments on fundamentals of vacuum science such as units, ideal gas law, partial pressure, mean free path, flow of molecules, conductance, pumping speed and outgassing. An overview of standard vacuum instruments for pressure measurement and pumping is presented. Finally, the specificities of beam –vacuum system interactions in an accelerator are introduced discussing synchrotron radiation, electron cloud and vacuum instability with their side effects of stimulated molecular desorption.

Presenter: BAGLIN, Vincent (CERN)

Contribution ID: **26** Type: **not specified**

Longitudinal Beam Dynamics II

Wednesday 11 May 2022 09:55 (1 hour)

Please see “Longitudinal Beam Dynamics I” for the complete set of slides.
“The lectures present an introduction to longitudinal beam dynamics on a basic level, focused rather on the concepts than the mathematical details.
It covers the basic methods of acceleration in a linac, presents different circular accelerator types, and focuses more on the longitudinal beam dynamics in synchrotrons.
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Finally, the RF manipulations in the PS for the generation of the bunch structure of the LHC beam are explained.

Presenter: Dr TECKER, Frank (CERN)

Contribution ID: **27** Type: **not specified**

RF Systems

Wednesday 11 May 2022 13:50 (1 hour)

Radio-frequency (RF) systems deliver the power to change the energy of a charged particle beam, and they are integral parts of linear and circular accelerators. A longitudinal electrical field in the direction of the beam is generated in a resonant structure, the RF cavity. As it directly interacts with the bunches of charged particles, the cavity can be considered as a coupler to transport energy from an RF power amplifier to the beam. The power amplifier itself is driven by a low-level RF system assuring that frequency and phase are suitable for acceleration, and feedback loops improve the longitudinal beam stability. The spectrum of RF systems in particle accelerators in terms of frequency range and RF voltage is wide. Special emphasis is given to the constraints and requirements defined by the beam, which guides the appropriate choices for the RF systems.

Presenter: DAMERAU, Heiko (CERN)

Contribution ID: **28** Type: **not specified**

Beam Instrumentation

Wednesday 11 May 2022 11:25 (1 hour)

This lecture gives an introduction to Beam instrumentation in particle accelerators.
It describes the physical processes and the technologies involved in the monitoring of beam intensity, beam position, transverse and longitudinal beam profiles as well as beam losses.
The lecture also presents a series of examples of instruments currently used at CERN.

Presenter: LEFEVRE, Thibaut (CERN)

Contribution ID: **29** Type: **not specified**

Cryogenics

Thursday 12 May 2022 09:55 (1 hour)

Cryogenics is the field of physics and engineering that deals with the production and effects at very low temperatures. The Large Hadron Collider (LHC) is the largest cryogenic system in the world and one of the coldest places on Earth. The LHC's superconducting magnets operate at a temperature of 1.9 K immersed in pressurized superfluid helium (He II@ 1.3 bar) and the accelerating cavities at 4.5 K in saturated helium (He I). Cooling enables superconductivity for accelerators and detectors as well as to study low temperature properties of materials and components. Other cryogenic fluids are used at CERN to operate particle detectors with e.g. liquid Argon or liquid Krypton. The lecture is giving an introduction to the cryogenics approach of cooling equipment to low temperatures with the goal to enable superconductivity or reducing the thermal background in measurement setups. Heat transfer mechanisms and cooling techniques are discussed, typical cryostat designs with the main influencing parameters are introduced, followed by the cooling scheme of the LHC with its sophisticated distribution system. The lecture will cover the unique features of superfluid helium cooling and how it is applied on the example of the LHC.

Presenter: KOETTIG, Torsten (CERN)

Contribution ID: **30** Type: **not specified**

Linacs

Tuesday 10 May 2022 16:30 (1 hour)

In this lecture we review the fundamental principles of a linear accelerator, we look at different types of RF structures both in the TE and TM mode and we discuss their use at different velocities and/or charge over mass. We also discuss basic principles of dynamics (transverse and longitudinal phase advance) during acceleration. The lecture builds on examples taken by the present and past hadron linacs at CERN.

Presenter: LOMBARDI, Alessandra (CERN)

Contribution ID: **32** Type: **not specified**

Welcome

Monday 9 May 2022 08:30 (15 minutes)

Presenter: TECKER, Frank (CERN)