

# A GENERAL OVERVIEW ON THE 2017 ICFA MINI-WORKSHOP ON IMPEDANCES AND BEAM INSTABILITIES IN PARTICLE ACCELERATORS

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## Abstract

The ICFA mini-Workshop on impedances and beam instabilities in particle accelerators, which took place in Benevento (Italy) from 18 to 22 September 2017, was intended to continue the tradition of dedicated conferences on the subject of beam coupling Impedances in particle accelerators, initiated with the 2014 ICFA mini-Workshop on “Electromagnetic Wake Fields and Impedances in Particle Accelerators” held in Erice (organized by Vittorio Vaccaro, Maria Rosaria Masullo and Elias Métral). The aim of the event was therefore to provide an up-to-date review of the subject, while widening its scope to include recent advances on beam instabilities and different instability sources.

The workshop was hosted by the University of Sannio at Benevento, under the auspices of the Italian Institute for Nuclear Physics (INFN), the Italian Physical Society (SIF) and CERN - and with the sponsorship of the European network ARIES, as well as the running projects for LHC Injectors Upgrade (LIU), Collimation and High Luminosity LHC (HL-LHC).

## INTRODUCTION

The ICFA Mini-Workshop on Impedances and Beam Instabilities in Particle Accelerators, was held in Benevento, Italy, from 18 to 22 September, 2017. The workshop was backed by a well assorted International Advisory Committee, who actively provided their inputs to define and shape the varied scientific program. The conference venue, the San Vittorino complex, is at the heart of the old town of Benevento. The workshop was supported and sponsored by several projects and networks (High Luminosity LHC, LHC Injectors Upgrade, LHC Collimation, ARIES), INFN (Napoli) and University of Sannio, and it was held under the auspices of the Italian Physical Society (SIF).

The main goal was to review relevant material in the field of impedances and beam instabilities and address recent advancements and breakthroughs. The workshop was attended by 84 participants from different laboratories all around the world (see Fig. 1), and more than a half were young accelerator physicists at the beginning of their careers. To best suit the young audience as well as the academic environment of the University of Sannio, speakers were requested to present their work providing an educational background of their subjects, before highlighting also the novelties, challenges and open questions.

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## WORKSHOP ANNIVERSARIES, STRUCTURE AND TOPICS

Given the timing, the workshop also provided an excellent setting to mark the occasion of two round anniversaries.

- 50 years of the Beam Coupling Impedance concept, introduced by Prof. Vittorio Vaccaro to describe the electromagnetic interaction of a particle beam with the external environment. Prof. Vaccaro entertained the audience with a historical talk describing the birth of the concepts of beam coupling impedance and stability charts. He specially stressed how the two concepts of impedance and representation of beam stability in complex stability diagrams were logically linked and were born together. He was warmly thanked by the workshop participants and awarded a memorial plaque for his important achievements.
- 10 years of Francesco Ruggiero’s passing away. F. Ruggiero was an outstanding accelerator physicist, who gave enormous contributions to the fields of impedances and instabilities, in particular by fostering the necessity of building detailed impedance models of machines and by working on the improvement of the models to describe beam instabilities. Applied to LHC, his vision led to the implementation of a strict impedance budget control during the phase of LHC design, the identification of collimators as major impedance source as well as of octupole magnets as fundamental means of stabilisation, and the recognition of the relevance of electron cloud in the LHC beam parameter range. His foresight has been instrumental to both guide the understanding of the current LHC operation and lay the ground for the general design strategy of all future machines with challenging beam parameters.

The workshop featured plenary sessions with 48 talks and 5 final summary reports. A Poster Session was also organised, during which 22 posters were displayed in the Santa Sofia Cloister. The general impression was that, although the subjects of beam coupling impedance and instabilities are 50 years old, they remain fashionable and up-to-date, because

- Old concepts need to be adapted and extended to new types of accelerators (e.g. FELs, plasma wake-field accelerators);



Figure 1: Workshop participants, group picture.

- Observations (or diagnostics) of new phenomena are made in running machines and need to be interpreted;
  - Exploring new parameter regimes for upgrades or future machines requires original approaches and studies;
  - Modeling and understanding of the phenomena related to impedance and instabilities are still making a steady progress benefiting from the advancement of technology;
  - Open theoretical questions are still being intensively studied and widely debated.
- New regimes are being explored (e.g. frequencies beyond 100 GHz, small structures).

## DISCUSSIONS AND OUTCOME

In the field of beam coupling impedance, a few main points emerged from the various discussions.

- When a new device for either old or new accelerators is designed to its performance specifications, it is crucial to include impedance reduction at the design stage, possibly also including all considerations coming from multi-physics simulations associated to the impedance effects.
- The evaluation of beam coupling impedances of accelerator devices becomes increasingly challenging due to several factors:
  - Devices become more and more complicated and require accurate electromagnetic descriptions;
  - Accelerators have more and more demanding performance requirements, which requires special attention to their impedance budgets. This leads to the necessity of enacting a strictly low impedance design policy;
- Electromagnetic codes to calculate numerically beam coupling impedances and wake functions are becoming ever more powerful and new ones are being produced using more advanced computational techniques (e.g. the moving window). This allows the detailed analysis of structures that could not be efficiently simulated before.
- Beam based measurements of beam coupling impedances are of fundamental importance to understand and pinpoint the limitations of running machines, in particular to identify:
  - Missing impedances in the global impedance model of a certain machine;
  - Impedance contributions of newly installed hardware through comparative measurements over successive machine runs;
  - Non-conformities, malfunctioning or ageing equipment leading to a degradation of impedance and possibly undesired effects on the beam;
  - Main contributors to the global impedance and relative mitigation techniques to reduce them in view of upgrades.

Establishing detailed impedance models of machines would be useless if this information could not be fed in beam dynamics calculations capable of assessing beam stability under the effect of the impedance.

Therefore, the techniques of modeling of beam instabilities were discussed at length and reviewed in detail.

- Two-particle models are still being used and extended to new cases (to include space charge, feedback systems, chromaticity). They are fairly simple, didactic and capable of unveiling the basic physics mechanisms behind coherent instabilities. An interesting generalization of these models is the circulant matrix formalism (Bim-Bim code), which is based on a radial and azimuthal slicing of the longitudinal phase space making it effectively an N-particle model that takes into account the full complexity of the longitudinal phase space structure of the beam in the study of the transverse stability.
- Vlasov solvers are widely used (e.g. MOSES, NHTS, DELPHI) to explore stability areas of complex machines in multi-dimensional parameter spaces. Their advantages and disadvantages were highlighted. Solvers of this type are:
  - Fast and suited to parameter scans;
  - Able to reveal slow growing modes;
  - Usually based on approximations/simplifications that need to be kept in mind before drawing strong conclusions from their results.
- Macroparticle simulations are also widely used (e.g. PyHEADTAIL, Elegant, COMBI, BLonD) and benefit from the increasing computing power that makes this approach more and more attractive. They:
  - Are relatively simple to implement and to be extended to include several effects (e.g. active loops, feedforward);
  - Provide full 6D monitoring of the beam evolution and their outputs can be used to make direct comparisons with beam measurements (e.g. pick up signals, emittance evolution, Schottky, BTF);
  - Need an appropriate choice of the numerical parameters (based on physics as well as numerical considerations) and convergence studies;
  - Are limited by computational times (memory, CPU time) and have a limited observation window, which may conceal slow growing modes.

It was underlined how, while the main driver for beam instabilities is usually the machine beam coupling impedance, many other mechanisms then come into play and affect instability thresholds.

- Space charge: Models suggest it acts against the onset of Transverse Mode Coupling Instability, although some machine observations do not confirm this (e.g. the SPS TMCI thresholds). Besides, its influence on the loss of decoherence could play a detrimental role by helping coherent signals to remain long-lived.
- Beam-beam, electron cloud, ions: They have been clearly described as, and proved to be, exciters of coherent motion that couples not only different bunches but

also head and tail of single bunches. On the other hand they also introduce important betatron tune spreads that should counteract the onset of beam instabilities. Including these mechanisms in the wake/impedance formalism is not straightforward, and maybe not even possible. However, the dynamics of these effects, together with the interplay between them and with the machine impedance, is in many cases fundamental to build a global picture of beam stability.

Finally, several mechanisms to suppress beam instabilities and potentially extend the performance reach of present and future machines were reviewed and illustrated, covering in particular the items listed below.

- Optimise machine optics, both linear and nonlinear, for collective effects. This has been shown to be the key to several knobs to reduce sensitivity to coherent motion, in particular:
  - Setting of tunes and linear chromaticities;
  - Control of nonlinear chromaticity, for instance its second order term  $Q''$ ;
  - Use of octupoles to generate transverse amplitude detuning;
  - Control of linear coupling, which can be beneficial, when transferring more stability from one transverse plane to the other, or detrimental, when it moves the coherent tunes out of the range for Landau damping;
  - Change of the transition energy.
- Rely on Landau damping by using conventional methods like octupole detuning or by exploring the efficiency of novel sources of betatron tune spread like Radio Frequency Quadrupole (RFQ) or electron lenses, which have not been yet used for this purpose in running machines but hold promise for upgrades and future machines.
- Employ feedback systems to damp coherent instabilities. Typically, the bandwidth of these systems have made them suitable to suppress coupled bunch instabilities of dipolar type, but they have remained inefficient against single bunch instabilities with strong head-tail coupling. However, in their most cutting edge development, these systems have been demonstrated to be capable of damping transverse intra-bunch modes for short bunches (which requires high bandwidth and a complex electronics chain) or quadrupolar type oscillations in the longitudinal plane (which requires special configuration of the hardware and could be of uttermost interest for machines like the CERN PS).

## CONCLUSIONS AND FUTURE

To conclude, the workshop provided a great platform to expose and debate all the scientific questions above, while at the same time it gave the participants a chance to enjoy the atmosphere and the sense of community fostered by the intense social program, which included a tour of the archaeological site of Pompeii and a concert performed by Trio Pragma, at the Museum of Sannio.

The subject of beam instabilities and instability sources in particle accelerators (e.g., impedance, electron cloud, ions) is far from being exhausted and the community is motivated to exchange experience and join efforts to advance further. The amount of open questions, the continuing progress recorded on different fronts and the promising outlook of many studies in terms of development and search for solutions fully legitimate the quest to pursue this series of workshops and to envisage a continuation in two or three years time.

More information on this workshop, including program and slides of the single talks, can be found on the [web site](#) and [Indico page](#) of the workshop.

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