Deterministic beam-schedule optimisation for the LHC injector chain

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Abstract

The LHC relies on an injector chain of four synchrotrons and two LINACs. Besides solely being injectors, each of these accelerators has its own users and experiments to furnish with beams as well, and they can only do this in the time between subsequent injections to their larger neighbour.

This presents quite a complex parallel-scheduling task, but it is vital that it is done well; any sub-optimality leaves CERN creating fewer useable beams per unit time than was actually possible, and any errors could cause serious problems. The task is made more challenging by the existence of numerous constraints on how beams can preceed/follow each other (e.g for avoiding remnant fields, or respecting hardware limitations) which must be obeyed, and also by the fact that the schedule is changed regularly (i.e. whenever any user in any accelerator changes their request).

Scheduling problems are already approached very well by numerous heuristic algorithms, which overcome the overwhelming size of the permutation search-space using skillful guesswork, but at the expense of thoroughness.

Here, we present a non-heuristic but practical scheduling algorithm which does not sacrifice thoroughness in its search. It fully maps the search-space of all valid schedules (up to topological equivalence) by compiling it into a navigable directed graph of localised decision points, and outputs a valid schedule which has truly optimal time-efficiency. Furthermore, if the algorithm finds no solutions, it can be trusted that the input request is indeed impossible to satisfy.

We also demonstrate an implementation of the algorithm as a Java program, which will be used in regular operations at CERN for computing optimal schedules for the whole injector chain.